Wetland Health and Importance Research Programme

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Tools and Metrics for Assessment of Wetland Environmental Condition and Socio-Economic Importance

Handbook to the WHI Research Programme

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WATER RESEARCH COMMISSION

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WETLAND HEALTH AND IMPORTANCE RESEARCH PROGRAMME

1

TOOLS AND METRICS FOR ASSESSMENT OF WETLAND ENVIRONMENTAL CONDITION AND SOCIO-ECONOMIC IMPORTANCE

HANDBOOK TO THE WHI RESEARCH PROGRAMME

Report to the
Water Research Commission

by

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Front Cover: Wetland near Sutherland, Western Cape, South Africa
Photograph: H. Malan

PREFACE

This report is one of the outputs of the Wetland Health and Importance (WHI) research programme which was funded by the Water Research Commission. The WHI represents Phase II of the National Wetlands Research Programme and was formerly known as "Wetland Health and *Integrity*". Phase I, under the leadership of Professor Ellery, resulted in the "WET-Management" series of publications. Phase II, the WHI programme, was broadly aimed at assessing wetland environmental condition and socio-economic importance.

The full list of reports from this research programme is given below. All the reports, except one, are published as WRC reports with H. Malan as series editor. The findings of the study on the effect of wetland environmental condition, rehabilitation and creation on disease vectors were published as a review article in the journal Water SA (see under "miscellaneous").

An Excel database was created to house the biological sampling data from the Western Cape and is recorded on a CD provided at the back of Day and Malan (2010). The data were collected from mainly pans and seep wetlands over the period of 2007 to the end of 2008. Descriptions of each of the wetland sites are provided, as well as water quality data, plant and invertebrate species lists where appropriate.

An overview of the series

Tools and metrics for assessment of wetland environmental condition and socio-economic importance: handbook to the WHI research programme by E. Day and H. Malan. 2010. (This includes "*A critique of currently-available SA wetland assessment tools and recommendations for their future development*" by H. Malan as an appendix to the document).

Assessing wetland environmental condition using biota

Aquatic invertebrates as indicators of human impacts in South African wetlands by M. Bird. 2010.

The assessment of temporary wetlands during dry conditions by J. Day, E. Day, V. Ross-Gillespie and A. Ketley. 2010.

Development of a tool for assessment of the environmental condition of wetlands using macrophytes by F. Corry. 2010.

Broad-scale assessment of impacts and ecosystem services

A method for assessing cumulative impacts on wetland functions at the catchment or landscape scale by W. Ellery, S. Grenfell, M. Grenfell, C. Jaganath, H. Malan and D. Kotze. 2010.

Socio-economic and sustainability studies

Wetland valuation. Vol I: Wetland ecosystem services and their valuation: a review of current understanding and practice by Turpie, K. Lannas, N. Scovronick and A. Louw. 2010.

Wetland valuation. Vol II: Wetland valuation case studies by J. Turpie (Editor). 2010.

Wetland valuation. Vol III: A tool for the assessment of the livelihood value of wetlands by J. Turpie. 2010.

Wetland valuation. Vol IV: A protocol for the quantification and valuation of wetland ecosystem services by J. Turpie and M. Kleynhans. 2010.

WET-SustainableUse: A system for assessing the sustainability of wetland use by D. Kotze. 2010.

Assessment of the environmental condition, ecosystem service provision and sustainability of use of two wetlands in the Kamiesberg uplands by D. Kotze, H. Malan, W. Ellery, I. Samuels and L. Saul. 2010.

Miscellaneous

Wetlands and invertebrate disease hosts: are we asking for trouble? By H. Malan, C. Appleton, J. Day and J. Dini (Published in Water SA 35: (5) 2009 pp 753-768).

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Dr Ian Russell
Mr Ramogale Sekwele
Mr Damian Walters
Ms Barbara Weston

Many people helped individual projects in the programme and for these acknowledgements the reader is referred to the relevant project. Nevertheless our appreciation is extended to each and everyone.

We would also like to express our gratitude to the team of formatters and proof-readers (Sally Hofmeyer, Genevieve Jones, Claire Mollat, Laura Malan and Diane Southey) who tirelessly combed through the hundreds of pages of WHI reports in order to help deliver the final products and to Laura Malan for producing the beautiful cover pages.

Finally, as programme coordinator I, Heather Malan, would like to thank my co-executive team members, Prof Jenny Day and Dr Liz Day for all their input in terms of advice, support and hard work during the course of the programme. Without them the final reports would never have seen fruition.

ABBREVIATIONS

AU – Animal Unit

DEAT – (formerly) Department of Environmental Affairs and Tourism

DWAF – (formerly) Department of Water Affairs and Forestry

EC – Electrical conductivity

EIA – Environmental Impact Assessment

EIS – Ecological Importance and Sensitivity

FCG – Freshwater Consulting Group

FRU – Freshwater Research Unit

GDP – Gross Domestic Product

GNI – Gross National Income

GNP – Gross National Product

HDS – Human Disturbance Index

HGM – Hydrogeomorphic

IBI – Index of Biotic Integrity

IEM – Integrated Environmental Management

JSS – Joint Study Sites

NAEHMP – National Aquatic Ecosystems Health Monitoring Programme

NDA – National Department of Agriculture

PES – Present Ecological State

RDM – Resource Directed Measures

RHP – River Health Programme

SADC – Southern African Development Community

SAM – Social Accounting Matrix

SANBI – South African National Biodiversity Institute

SASS – South African Scoring System

TOR – Terms of reference

UCT – University of Cape Town

VEGRAI – Riparian Vegetation Response Assessment Index

WHI – Wetland Health and Importance (Research Programme)

WIHI – Wetland Index of Habitat Integrity

WLVI – Wetland Livelihood Value Index

WRC – Water Research Commission

1. Introduction to the Wetland Health and Importance Series

1.1 What is the Wetland Health and Importance (WHI) Project?

In 2003, the Water Research Commission (WRC) launched a National Wetlands Research Programme, aimed at optimising wetland conservation, in the context of management, protection, rehabilitation and sustainable use. The programme was initiated in collaboration with other major role players, including the (then) [1]Department of Environmental Affairs and Tourism (DEAT), the (then) Department of Water Affairs and Forestry (DWAF) and the (then) National Department of Agriculture (NDA), and had four main objectives, namely:

- to initiate, support and manage research projects that contribute to wetland management;
- to ensure the effective transfer of information on wetlands to institutions and persons involved in wetland management;
- to promote human resource capacity in wetland management; and
- to ensure the financial long-term sustainability of wetland research in South Africa.

Three major research thrusts were identified, in order to meet the above broad scale objectives of the programme. These thrusts, subsequently divided into three phased research programmes, were as follows:

- Phase I: Wetland rehabilitation;
- Phase II: Assessment of wetland health and importance (Integrity) [2]; and
- Phase III: The wise use of wetlands.

Of the three thrusts, Phase I was launched in 2004 under the leadership of Professor Ellery, then of the[3] University of KwaZulu-Natal, with a major aim of the programme being to support the research requirements of the Working for Wetlands Public Works Programme. Phase I, which included the development of several tools for the assessment of different aspects of wetland condition and function, as well as protocols to assist in wetland prioritisation, rehabilitation planning, monitoring and other aspects of

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[1] Note that the Forestry division of DWAF has since been incorporated into the Department of Agriculture, Fisheries and Forests, and Water and Environmental Affairs have been linked into a single Department of Water and Environmental Affairs (DWEA).

[2] Formerly known as “Wetland Health and Integrity” the last word has been changed to “Importance” to better reflect the scope of the research programme.

[3] Professor Ellery is now based at Rhodes University.

relevance to general wetland rehabilitation and management, was completed in late 2008. It has resulted in the "WET-Management" series of publications – an overview of which is given in Dada *et al.* (2007).

Phase II comprises the present research programme and this document aims to distil the major findings of the different components of the project, and their implications for future work in management or assessment of wetland environmental condition and socio-economic importance in South Africa. Work on Phase III – The Wise Use of Wetlands – has not yet been initiated.

1.2 Components of the WHI programme

The terms of reference for the Assessment of Wetland Health and Importance phase of the National Wetlands Research Programme were derived largely from the findings of a strategic overview of research needs in wetland conservation and management, commissioned by the WRC and presented in Malan and Day (2005). While various methodologies have been developed for the assessment of riverine environmental condition, importance and ecological status (see section 3.2 for a discussion of these terms), Malan and Day (2005) highlighted the fact that few assessment approaches allow an objective assessment of wetland condition. This despite the fact that assessment of wetland condition, sometimes synonymously referred to as "health" and /or integrity (see Section 3.1) is fundamental to the effective management, monitoring and rehabilitation of wetlands, and is moreover a requirement for meeting the demands of the National Water Act. However, there is also a recognition that wetland assessment differs from that of rivers, in that the complexity and diversity of wetland ecosystems at a national and even a regional level, coupled with the equally diverse array of potential impacts and pressures that are placed on wetlands, mean that it is unlikely that any one assessment protocol will be able to address the requirements for undertaking wetland assessments at a range of scales and be applicable to all wetland types.

Malan and Day (2005) also stressed the growing recognition of the important "goods and services" provided by wetlands and the critical role they play in human development, both at a local and at a landscape level. In many areas of the country, sectors of the population are directly dependent on wetlands for subsistence use. At the same time, there is demand for resources such as water and land which are becoming increasingly scarce. There is a great need for tools that will help place a value (monetary or otherwise) on the benefits that wetlands supply to the people living around them, and to human society at large. Thus, to be able to make rational decisions concerning the management of wetlands themselves, in the context of development in the surrounding catchments, we need to be able to assess the social importance as well as the economic benefits that are (or potentially could be) generated from a wetland.

Malan and Day (2005) identified gaps in the availability of assessment tools, on which to base assessment of wetland environmental condition. They also noted deficiencies in the level of understanding of several fundamental aspects of wetland function, structure and response to both natural and anthropogenic drivers, including biological, hydrological, chemical and physical factors. Out of this was born the present wetland research programme, which aimed to fill some of these gaps, operating at a broad scale from biological through to economic and social aspects and incorporating assessment techniques for both local and landscape level systems and processes. This entailed division of the programme into a number of components, which can be coarsely divided into the following broad categories:

- projects involving biota (macro- and micro-flora and fauna) for assessment of wetland environmental condition;
- broad-scale wetland studies on wetland processes, carried out at a landscape level; and
- socio-economic studies.

In addition to the above, there were also a number of miscellaneous studies, which were included for convenience in the broad ambit of projects addressed by the WHI programme (see Table 1.1 for a full list of products), but which did not necessarily link directly in subject matter to the main aims and objectives of the programme (see Section 1.3 below). For instance, these miscellaneous projects included a review of the links between wetlands and invertebrate hosts of disease.

1.3 Over-arching aims

The main aims of the Wetland Health and Importance Research Programme are listed below.

1. To develop tools for assessing wetland environmental condition that will address the major needs of users in South Africa.

2. To develop tools for assessing wetland socio-economic importance that will begin to satisfy the needs of users in South Africa.
3. To develop a protocol to assess the loss of wetland function through degradation.
4. To implement a communication programme to advise on the use of assessment techniques developed in the programme.

The extent to which the aims were achieved is discussed in section 7.1.

1.4 Use and application of this document

This document provides summary information about the findings, the underlying assumptions and principles and the application and sensitivity of each of the main focal study categories of this programme (biotic, broad-scale/landscape level and socio economic studies). It is intended to guide users as to the array of assessment tools and methodologies that are available in South Africa at present that can be used to address different aspects of wetland environmental condition, as well as to provide basic input into the applicability of each of the tools under different conditions. The resource requirements (time, finances and human skills) of each protocol are also outlined, with the objective of contributing to efficient assessment planning and ensuring that assessments are carried out at a scale that is adequate to the questions that need to be addressed on a case by case basis.

1.5 List of products generated by the WHI programme

Table 1.1 summarises the outputs of the WHI programme. These have been presented in terms of the three major components of the programme, namely:

- projects involving assessment of wetland environmental condition using biota (macro and micro flora and fauna);
- broad-scale assessment of impacts to hydrological functioning and wetland ecosystem services; and
- socio-economic and sustainability studies, including the development of resource economics and sustainability metrics.

The miscellaneous reports are also listed, followed by the overview document, namely this report.

Table 1.1: Summary of outputs of the WHI Programme

Component	Task Name	Title	Authors
Biotic indices	Macrophyte index	Development of a tool for the assessment of the environmental condition of wetlands using macrophytes	F. Corry
	Invertebrate index	Aquatic invertebrates as indicators of human impacts in South African wetlands	M. Bird
	Dry condition indices	The assessment of temporary wetlands during dry conditions	J. Day, E. Day, V. Ross-Gillespie and A. Ketley
Landscape level assessment		A method for assessing cumulative impacts on wetland functions at the catchment or landscape scale.	W. Ellery, S. Grenfell, M. Grenfell, C. Jaganath, H. Malan and D. Kotze
Resource Economics	Resource-economics scoping study	**Vol I:** Wetland ecosystem services and their valuation: a review of current understanding and practice	J. Turpie, K. Lannas, N. Scovronick and A. Louw
	Case studies	**Vol II:** Wetland valuation case studies.	J. Turpie
	Dependency metric	**Vol III:** A tool for the assessment of the livelihood value of wetlands	J. Turpie
	Valuation protocol	**Vol IV:** A protocol for the quantification and valuation of wetland ecosystem services.	J. Turpie and M. Kleynhans
Sustainability index		WET-SustainableUse: A system for assessing the sustainability of wetland use.	D. Kotze
Miscellaneous	Application of the Sustainability indices and assessment tools	Assessment of the environmental condition, ecosystem service provision and sustainability of use of two wetlands in the Kamiesberg uplands	D. Kotze, H. Malan, W. Ellery, I. Samuels and L. Saul
	Disease vectors	Wetlands and invertebrate disease hosts: are we asking for trouble? (*Water SA* **35** (5) 2009)	H. Malan, C. Appleton, J. Day and J. Dini
		A critique of currently-available SA wetland assessment tools and recommendations for their future development (included as an appendix in this document)	H. Malan
Handbook to the WHI research programme		This document	E. Day and H. Malan

2. Background information for the WHI

2.1 The importance of wetlands in a national context

Wetlands are internationally recognised as important natural ecosystems (e.g. Cowan, 1995) which, depending on the characteristics of each wetland type, may perform some of the following valuable functions, including (Davies and Day, 1998):

- provision of habitat to wetland-associated animals and plants, many of which rely exclusively on these areas for breeding, feeding or nursery areas (Cowan, 1995);
- provision of corridors for movement between terrestrial natural areas, or along river systems;
- contribution to the perenniality of stream systems, through retention and slow release of waters during low flow periods;
- flood attenuation – effected by retention of flood waters in wetland soils, and reduction of flood velocities through dissipation of flows through wide, vegetated areas;
- improving water quality, through uptake and absorption of nutrients and other contaminants often found in surface runoff;
- trapping sediment and reducing erosion of stream channels;
- provision of harvestable resources, of value to human communities; and
- provision of areas of tourism and/ or recreational value to human communities.

South Africa is a signatory to the Ramsar Convention – an international treaty aimed at the conservation of wetland habitats (Cowan, 1995). This convention binds members to a set of criteria aimed at the conservation of wetland ecosystems. These criteria include: stemming the loss of wetlands, promoting the wise use of all wetland areas and promoting the special protection of listed wetlands.

2.2 Threats to wetlands in South Africa

Despite the acknowledged ecological, economic and educational value of wetlands, it was estimated some 14 years ago (Cowan, 1995) that over half of South Africa's wetlands had already been destroyed and lost. Since then, the loss and degradation of wetlands has continued, making those wetlands that remain among South Africa's most threatened natural areas.

In rural and agricultural areas, the loss of wetlands is associated with activities ranging from ploughing and drainage, through to diversion of flows from wetlands, groundwater abstraction and activities such as concentration of flows through channellisation or the construction of structures such as roads and bridges across or close to wetlands, often resulting in headcut erosion and shrinkage of wetland areas as well as fragmentation of remnant habitats. Degradation of wetlands can take the form of nutrient enrichment, as a result of livestock waste or return flows from fertilized lands; pollution of wetlands from toxicants in pesticides and herbicides, some of which accumulate in biological tissues, and other impacts such as compaction through livestock trampling, burning, inundation as a result of impoundment and invasion (accidental or as a result of plantations) by alien plants, leading in some cases to desiccation, shading and loss of indigenous wetland vegetation. Effluent from mines and industrial activities is frequently discharged to wetlands, including isolated pans.

The loss of wetlands in urban areas can be no less profound, and results from activities that include infilling, diversion of flows, drainage and channellisation, all of which are usually associated with the desire to create space for developments, including roads and other infrastructure. For wetlands that are not destroyed outright, hydroperiod can change markedly, with remnant wetlands either being drained and dried out, or subjected to increased flows as a result of raised water tables and/or increased runoff from hardened surfaces, often fed by water from other catchments. Nutrient enrichment is associated with the receipt by rivers and wetlands of both treated and untreated sewage effluent, while trampling by humans and, in some areas, livestock contributes to wetland degradation and the creation of erosion nick-points. Fragmentation on a large scale also occurs within urban areas dissected by route ways, which interrupt natural corridors and isolate populations of less mobile biota in small pockets of natural (or near-natural) vegetation.

Against the background of such threats, which occur at different levels of intensity on a national scale, there is a dire need for objective assessments of wetland environmental condition, to facilitate monitoring, management and the tracking and fine-tuning of rehabilitation outcomes. Tools which will aid in valuing wetland benefits are also essential in order to make sensible decisions concerning development in and around wetlands.

2.3 Classification of wetlands

The National Wetland Classification (SANBI, 2009) defines wetlands in terms of an adaptation of the Ramsar wetland definition, as:
"areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tides does not exceed ten meters. Wetlands are areas where water is the primary factor controlling the environment and, therefore, wetlands develop in areas where soils are saturated or inundated with water for varying lengths of time and at different frequencies".

The national wetland classification of SANBI (2009) has a six-tiered structure, summarised in Table 2.1 after SANBI (2009) with four spatially-nested primary levels that are applied in a hierarchical manner to distinguish between different wetland types on the basis of "primary discriminators" (i.e. criteria to consistently distinguish between different categories at each level of the hierarchy). The hierarchical structure progresses from "Systems" (Marine vs. Estuarine vs. Inland) at the broadest spatial scale (Level 1), through to "Hydrogeomorphic (HGM) Units" at the finest spatial scale (Level 4). The following sections summarise the major tenets of the classification system, using information adapted from SANBI (2009).

- **Level 1** distinguishes between the three major systems – *the WHI programme focuses however only on Inland Wetland Systems, with a particular focus on palustrine wetlands – that is, wetlands dominated by emergent vegetation, rather than deep, open waterbodies.*
- **Level 2** allows for categorisation of wetlands in terms of regional settings. This level, which is based (for Inland systems) on the National Eco-regions Map (Level 1), as presented by Kleynhans *et al.* (2005) and illustrated in Figure 2.1 (after SANBI, 2009). These eco-regions reflect, as the key discriminators of wetland types, a combination of biophysical attributes within landscapes that operate at a broad, bio-regional scale, rather than specific attributes such as soils or vegetation. South Africa has been divided into 31 discrete eco-regions.
- **Level 3** for Inland Systems distinguishes between four Landscape Units (slope, valley floor, plain and bench/hilltop) on the basis of their topographic position, in recognition of the fact that the hydrological and hydrodynamic processes acting within wetlands may be affected by differences in this attribute.

- **Level 4** classifies wetlands in terms of HGM Units, which are defined primarily according to:

    landform (which defines the shape and setting of a wetland);

    hydrological characteristics, which describe the nature of water movement into, through and out of the wetland; and

    hydrodynamics, which describe the direction and strength of flow through the wetland.

  Together these factors affect the geomorphological processes acting within the wetland such as erosion and deposition, as well as biogeochemical processes (after SANBI, 2009).

  The WHI programme excluded channel (river) systems.
- **Level 5** for Inland systems focuses on hydrological regime (seasonally saturated, seasonally inundated, etc.) and inundation depth-class.
- **Level 6** makes use of six wetland “descriptors”, used to characterize wetland types on the basis of consistent criteria relating to biophysical features. These non-hierarchical descriptors can be applied in any order, and include:

    geology;

    degree to which a wetland is natural versus artificial;

    vegetation cover type;

    substratum;

    salinity; and

    acidity / alkalinity.

2.4 Wetland types included in the WHI series

The WHI programme has deliberately excluded river channel hydrogeomorphic units, on the basis that adequate assessment methodologies have already been developed to allow assessment of the condition of these freshwater ecosystems. Moreover, the programme also focuses on palustrine rather than lacustrine wetlands, with the development of assessment tools for large inland or coastal lakes and estuaries having been specifically excluded from the outcomes of this programme. Hydrogeomorphic units that were studied in this programme included depressions, floodplains and channelled or unchannelled valley bottom wetlands.

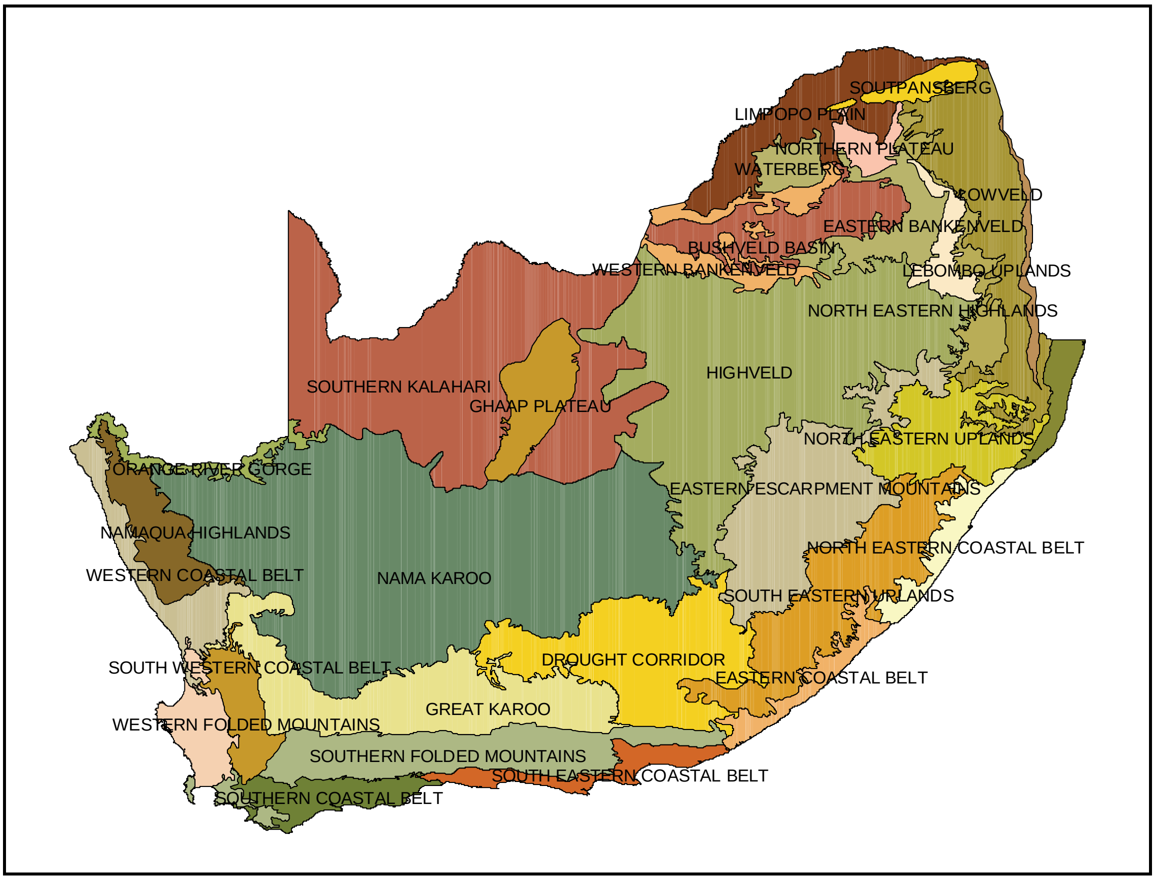

Figure 2.1: Map of DWAF Level I Eco-regions (extracted from SANBI (2009) after Kleynhans *et al.*, 2005).

Table 2.1: Classification structure for Inland Systems, up to Level 4 – after SANBI (2009)

LEVEL 1: SYSTEM	LEVEL 2: REGIONAL SETTING	LEVEL 3: LANDSCAPE UNIT	LEVEL 4: HYDROGEOMORPHIC (HGM) UNIT			
CONNECTIVITY TO OPEN OCEAN	*ECOREGION*	*LANDSCAPE SETTING*	*HGM TYPE*	*LONGITUDINAL ZONATION / LANDFORM*	*DRAINAGE - OUTFLOW**	*DRAINAGE - INFLOW**
			A	B	C	D
INLAND	DWAF Level I Ecoregions	SLOPE	**Channel (river)**	Mountain headwater stream	[not applicable]	[not applicable]
				Mountain stream	[not applicable]	[not applicable]
				Transitional river	[not applicable]	[not applicable]
				Rejuvenated bedrock fall	[not applicable]	[not applicable]
			Hillslope seep	[not applicable]	With ch. outflow	[not applicable]
					Without ch. outflow	[not applicable]
			Depression	[not applicable]	Exorheic	With ch. inflow
						Without ch. inflow
					Endorheic	With ch. inflow
						Without ch. inflow
					Dammed	With ch. inflow
						Without ch. inflow
		VALLEY FLOOR	**Channel (river)**	Mountain stream	[not applicable]	[not applicable]
				Transitional river	[not applicable]	[not applicable]
				Rejuvenated bedrock fall	[not applicable]	[not applicable]
				Upper foothill river	[not applicable]	[not applicable]
				Lower foothill river	[not applicable]	[not applicable]
				Lowland river	[not applicable]	[not applicable]
				Rejuvenated foothill river	[not applicable]	[not applicable]
				Upland floodplain river	[not applicable]	[not applicable]
			Channelled valley-bottom wetland	Valley-bottom depression	[not applicable]	[not applicable]
				Valley-bottom flat	[not applicable]	[not applicable]
			Unchannelled valley-bottom wetland	Valley-bottom depression	[not applicable]	[not applicable]
				Valley-bottom flat	[not applicable]	[not applicable]
			Floodplain wetland	Floodplain depression	[not applicable]	[not applicable]
				Floodplain flat	[not applicable]	[not applicable]
			Depression	[not applicable]	Exorheic	With ch. inflow
						Without ch. inflow
					Endorheic	With ch. inflow
						Without ch. inflow
					Dammed	With ch. inflow
						Without ch. inflow
			Valleyhead seep	[not applicable]	[not applicable]	[not applicable]
		PLAIN	**Channel (river)**	Lowland river	[not applicable]	[not applicable]
				Upland floodplain river	[not applicable]	[not applicable]
			Floodplain wetland	Floodplain depression	[not applicable]	[not applicable]
				Floodplain flat	[not applicable]	[not applicable]
			Unchannelled valley-bottom wetland	Valley-bottom depression	[not applicable]	[not applicable]
				Valley-bottom flat	[not applicable]	[not applicable]
			Depression	[not applicable]	Exorheic	With ch. inflow
						Without ch. inflow
					Endorheic	With ch. inflow
						Without ch. inflow
			Flat	[not applicable]	[not applicable]	[not applicable]
		BENCH (HILLTOP / SADDLE / SHELF)	**Depression**	[not applicable]	Exorheic	With ch. inflow
						Without ch. inflow
					Endorheic	With ch. inflow
						Without ch. inflow
			Flat	[not applicable]	[not applicable]	[not applicable]

NOTE: 2^{nd} row of Table provides the criterion for distinguishing between wetland units in each column

* ch. = channelled (outflow/inflow)

3. ASSESSING WETLAND ENVIRONMENTAL CONDITION

3.1 Terminology: the concept of wetland "health"

The title of the WHI programme includes the somewhat contentious term "wetland health", which emanates from Phase 1 of the National Wetland Research Programme, in which the assessment protocol "WET-Health" defines wetland health as "a measure of the similarity of a wetland to a natural reference condition" (Macfarlane *et al.,* 2008).

The use of the term "health" with reference to a particular ecosystem condition has received much attention in ecological and management policy literature. On the one hand, it is a useful metaphor to which a broad range of human society can relate, and thus provides a potential bridging terminology between scientists, the general public and policy makers (Meyer, 1997). Implicit in the use of the term "health" is usually an assumption that a "healthy" system is one that is pristine, natural or minimally altered by human activities, and many proponents of the concept of ecosystem health, like Macfarlane *et al.* (2008) use the terms "health" and "integrity" more or less interchangeably. However, Wicklum and Davies (1995) note that one of the problems in the use of these terms is that they are not inherent properties of ecosystems, but rather are based on an inevitable anthropocentric interpretation of some kind of a desired ecosystem condition that is perceived to be "healthy". That is, ecosystem "health" implies some kind of a scale, the calibration of which is subjective (Callicott, 1995), with someone having to decide what ecosystem condition or function is "good" (Sagoff, 1995). These decisions are inevitably biased by societal perceptions of "desirable" ecosystem properties. Moreover, a highly altered ecosystem may function in a "healthy" manner, if criteria such as sustainability and maintenance of biodiversity are used in definitions of ecosystem health (Lackey, 2001). NAU (2007) explicitly advocates the use of selected ecological indicators and the collective value judgements of ecosystem stakeholders to describe ecological health, in terms of a relative condition.

Other authors (e.g. Karr and Chu, 1999) argue that the concepts "integrity" and "health" are quite different, with health being defined as "the preferred [by human society] state of ecosystems modified by human activity" while integrity is defined as "an unimpaired condition in which ecosystems show little or no impact from human actions" and ecosystems with a high degree of integrity would be natural or pristine. Karr *et al.* (1986) describe (biotic) integrity as "the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of the natural habitat of the region".

In the context of the present WHI programme, it was resolved that the term "wetland heath" was too fraught with controversy for its use in the development of wetland assessment tools to be constructive. The use of the term has thus been confined to the outcomes of the existing WET-Health methodology, with different components of the WHI programme rather focusing on the development of metrics for the assessment of "environmental state" or "condition", with the understanding that these terms imply a particular position on a scale, which could range from pristine (i.e. in the natural state) to completely impacted.

3.2 Existing tools for the assessment of wetland condition

At the time of writing this report, a number of other tools outside of those developed by the WHI programme had already been developed, as part of other independent or previous initiatives. These include the outcomes of the first phase of the National Wetlands Research Programme, as well as initiatives by the (then) Department of Water Affairs and Forestry (DWAF) to develop rapid assessment tools that would be compatible with the requirements for Determination of the Ecological Reserve for wetland systems. One of the products of the WHI programme included a review of these tools, which was compiled by Malan in 2008, and is included as an Appendix to the present report. The substance of Malan (2008)'s findings have been summarised below, and provide a useful context in which to present the outcomes of the assessment metrics/ methodologies that have been developed as part of the current WHI programme, and to identify remaining gaps in assessment processes.

Malan (2008) evaluated three existing assessment tools, namely:

- WET-Health: a technique for rapidly assessing wetland health (Macfarlane *et al.,* 2008);
- The Wetland Index of Habitat Integrity (DWAF, 2007); and
- WET-EcoServices: a technique for rapidly assessing ecosystem services supplied by wetlands (Kotze *et al.,* 2008a).

The first two assessment methods set out to assess aspects of wetland environmental condition, whereas the third considers the extent of the "goods and services" supplied by a given wetland. All are currently being utilised by wetland practitioners. Malan (2008) stressed the importance of collating the experiences and findings of these practitioners, to allow refinement and standardisation of assessment measures and protocols, and to ensure that assessors employ the same level of internal scaling. One of the reports from the WHI programme ("Assessment of the environmental condition, ecosystem service provision and sustainability of use for two wetlands in the Kamiesberg uplands," by Kotze *et al.* 2010) describes application of WET-Health and WET-EcoServices in conjunction with WET-SustainableUse, developed during the WHI programme, to a case study in Namaqualand.

A WET-Health

The WET-Health methodology comprises two assessment levels (level 1 and 2), with level 1 being a relatively rapid but more superficial approach, while level 2 involves a more in-depth assessment of wetland condition based on observed, or measured attributes and on expert opinion. The WET-Health methodology incorporates three modules, namely wetland hydrology, geomorphology and vegetation. Assessments are carried out at the level of the HGM unit. The tool does not allow for a detailed assessment of impacts derived from, or resulting in, changes in water quality. The approach serves as a useful framework which complements assessments of environmental condition made using the biota.

Although the Level 2 WET-Health produces a more in-depth understanding of wetland function and impairment, Malan (2008) notes that its likely application is potentially limited by the length of time taken to conduct a full Level 2 assessment for a single wetland – an estimated time requirement of about two days just to complete field work and datasheet calculations. Thus Level 1 assessments are often applied when there are large numbers of wetlands to be assessed, and the coarser scale of this level is to some extent "calibrated" by more detailed Level 2 assessments at key wetlands.

Malan (2008) notes that the WET-Health Level 2 approach has a potential application in terms of Intermediate or Comprehensive Reserve determinations, for establishing the Present Ecological State and trajectories of change within a wetland. This is facilitated by its scoring of Present Ecological State (PES) in terms of DWAF categories A to E. Although some work has been done (e.g. the Rapid Reserve Determination for Franklinvlei wetland (Rountree *et al.,* 2007)) to calibrate the outcome categories from this assessment technique with other PES assessment outputs, further refinement through application to test cases is still required.

Limitations of environmental condition assessments based on WET-Health include:

- its application to valley bottom and floodplain wetlands only – that is, the methodology is not applicable to depressions, hillslope and valleyhead seeps and wetland flats;
- the fairly extensive length of time required for a Level 2 assessment; and
- the absence of a detailed water quality module.

B Wetland Index of Habitat Integrity (WIHI)

This tool was developed for use in the National Aquatic Ecosystem Health Monitoring Programme (NAEHMP), formerly known as the River Health Programme (RHP) (DWAF, 2007). It was developed to allow the NAEHMP to include assessment of floodplain and channelled valley bottom wetland types, and for the incorporation of these data into the monitoring programme. The output scores from the WIHI model are presented in standard DWAF A-F ecological categories and provide a Habitat Integrity score for the Present Ecological State (PES) of the wetland in question. It thus, like the WET-Health Level 2 assessment, lends itself to determination of the ecological reserve for wetlands.

The WIHI tool includes a water quality component, although this is not very well-developed, and also does not allow for assessments of other wetland HGM types, leaving depressions, wetland flats and hillslope and valleyhead seeps without an appropriate assessment tool. A second phase of the project to address some of these short-comings is planned.

The WIHI approach is similar to that of WET-Health Level 1 assessments in terms of the time component required for assessment, and also results in a broad-based assessment output, which does not include the depth of understanding allowed by a WET-Health Level 2 assessment. Reporting provided by the WIHI approach is user-friendly and facilitates subsequent visits and monitoring. Moreover, it is informed by field assessments, while a level 1 WET-Health assessment relies primarily on desktop assessment of aerial photographs (Macfarlane *et al.,* 2008).

C WET-EcoServices

The overall goal of the WET-EcoServices tool is to provide a reliable and relatively rapid means for assessing the ecosystem services that a given wetland is likely to supply to the surrounding human community. Assessments are carried out at the level of wetland HGM units, and the range of ecosystem services assessed include so-called regulating services such as flood control, supporting services such as nutrient cycling, provisioning services such as food and water and cultural services such as recreational and cultural benefits. Guidelines are provided for scoring the importance of a wetland in delivering each of 15 different ecosystem services (e.g. flood attenuation, sediment trapping, provision of livestock grazing, etc.).

The tool does not include assessment of functions such as groundwater recharge, discharge and biomass export, all of which may be of importance but are considered by Kotze *et al.* (2008a) as difficult to characterize at a rapid assessment level.

Ecosystem service delivery is assessed either at Level 1, based on existing knowledge or at Level 2, based on a field assessment of key descriptors (e.g. flow pattern through the wetland). Both approaches are fairly rapid and straight-forward to use. Kotze *et al.* (2008a) describe the principal functions of the WET-EcoServices tool in terms of allowing:

- assessment of the importance of wetlands in the context of broad-scale conservation or catchment planning or a Reserve Determination study;
- assessment of the importance of a wetland for livelihoods;
- initial scoping of important environmental features to be accounted for in relation to a proposed development; and
- assessment of the general likely effects of proposed developments or rehabilitation interventions on ecosystem service delivery.

Wet-EcoServices can be applied to any palustrine wetlands, and thus includes depressions, hillslope seeps and flats as well as valley bottom and floodplain wetlands.

Kotze et al. (2008a) note however that, unlike the WET-Health and the WIHI, WET-EcoServices does not lend itself directly to the determination of PES. It does, however, facilitate determination of the Environmental Importance and Sensitivity (EIS) which is considered during PES determination for an ecological reserve study. Furthermore:

- the system is not designed to assess the specific level of impact of a current or proposed development;
- it does not provide a single overall measure of the relative value or importance of a wetland, because it does not factor wetland size into the assessment;

- it does not quantify (in monetary or other terms) the benefits supplied by a wetland, although it does allow qualitative comparison between wetlands, using indices;
- it does not assess the integrity of a wetland; and
- the system does not account for the cumulative value of a group of wetlands.

Note, however, that one of the projects under the WHI programme (Ellery *et al.* 2010) investigates the relationships between the level of environmental condition and the extent that a given ecosystem service will be provided. This approach specifically takes into account wetland size, thus allowing quantitative comparison of the ecosystem services provided by different wetlands. Another WHI project (Turpie and Kleynhans 2010) presents a protocol for valuing the benefits conferred by a given wetland (Table 1.1).

4. GUIDING PRINCIPLES IN THE DEVELOPMENT OF TOOLS FOR WETLAND ASSESSMENT

One of the main points of focus for the WHI programme was the compilation, testing and evaluation of the feasibility of the various tools used for assessing different aspects of wetland condition, ecosystem service or importance. It was, however, recognized at the outset of the project that the development of these tools, which vary from simple assessment protocols through to complex inter-disciplinary metrics, needed to take cognizance of a number of broad principles:

- any metrics/tools developed during the programme needed to be based on tested, scientifically validated and defendable data;
- any metrics/tools developed would need to be tested rigorously – either as part of the present programme or in subsequent programmes. Testing would need to ascertain the robustness of each of the tools in different eco-regions, across different wetland HGM units and between different implementing agencies/individuals;
- the strengths, weaknesses and underlying assumptions of each of the tools would need to be stated explicitly in each report; and
- the inter-relatedness of different tools should be explored, to ensure cross-fertilisation of ideas but also to ensure that duplication of assessment criteria and approaches does not take place and to encourage the development and application of uniform assessment tools at a national level, thus avoiding the creation of splinter assessment groups and organizations. In this regard, the separate development of the WET-Health and WIHI methodologies has already been raised as an existing area of concern (Malan, 2008; Appendix 1 to this report).

The issue of the applicability of new assessment tools for use in DWAF's Resource Directed Measure (RDM) methodologies was also raised at an early stage of the overall project. The requirements from DWAF for such a tool included the following:

- the tool should preferably require no more than 3 to 4 hours of time, including site assessment, completion of datasheets and site write-up;
- the tool should preferably be useable by a trained technician – that is, it should not depend on interpretation by a specialist wetland practitioner; and
- one of the outcomes of the tool should be an assessment of wetland condition that is compatible with the DWAF Present Ecological Status Assessments (i.e. an A to E

categorization) and has been calibrated such that assessment categories are comparable.

Consideration of these requirements, and of the likelihood that several of the tools developed during the programme would not in fact meet all (or even any) of these criteria, highlighted the fact that different user groups inevitably had very different expectations of the programme, and of the kinds of tools that it would develop. Moreover, no tool is likely to be able to meet all the requirements of a variety of users, particularly bearing in mind the diversity of wetland systems, the range of potential impacts affecting wetlands on a national level and the paucity of baseline biophysical information that is relevant to gaining an in-depth understanding of the function and structure of different wetlands. The approach taken to this dilemma was that each tool states explicitly its application, user group and the strengths and weaknesses which underlie its development, as well as its application and/or interpretation.

Table 4.1 provides a summary of these aspects of each of the tools developed during the course of this programme. The individual tools themselves are discussed in more detail in Section 5.

Table 4.1: Summary of the major thrusts, intended users and assessor requirements for the application of tools / metrics and protocols developed as part of the WHI Programme

TOOL	INTENDED USER	PURPOSE	REQUIREMENTS (TIME, EXPERTISE ETC)	COMMENTS
INVERTEBRATE INDEX (Report title: Aquatic invertebrates as indicators of human impacts in South African wetlands By M. Bird)				
This project looked at the *feasibility* of developing an index for assessing wetland environmental condition using invertebrates. The results indicated that invertebrates (both macro- and micro-) were NOT suitable for seasonal depression wetlands in the W Cape. Nevertheless, a draft numerical index has been developed (including a protocol for trialling this in different HGM types and eco-regions). The numerical index now needs to be tried in different parts of the country. Wetland types for which SASS is applicable/not applicable are defined.				
MACROPHYTE INDEX (Report title: Development of a tool for the assessment of the environmental condition of wetlands using macrophytes. By F. Corry)				
1. A rapid bioassessment tool	SANBI, wetland specialists, land-owners/managers, DWAF (Rapid Reserves).	To assess and monitor wetland environmental condition.	4 hours/wetland for field-work, further 4 hours for analysis. Reasonable expertise required (i.e. be able to recognize common wetland and weed species).	It is proposed that the vegetation module of WET-Health be used for the Rapid appraisal approach.
2. A detailed bioassessment tool	SANBI, wetland specialists, DWAF (Intermediate and Comprehensive Reserves).		2 days/wetland. Expert knowledge of wetland plants required. Plant samples may need to be sent away for identification.	This approach will be able to indicate more subtle changes to wetland flora than the Rapid method.
DRY CONDITION INDEX (Report title: The assessment of temporary wetlands during dry conditions. By J. Day *et al.*)				
A rapid* bioassessment tool	SANBI, wetland specialists, municipalities, land-managers/planners. Possibly DWAF	To test for the presence of and assess environmental condition of temporary wetlands whilst in the dry state (potentially useful for EIAs and conservation of biodiversity).	Time requirement is up to 35 days as the sediment samples need to be incubated. Expertise in identifying propagules required as well as specialised equipment to control environmental conditions (light and temperature).	*The tool will only give an indication of environmental condition. It will not be rapid in the usual sense because samples need to be incubated.

ASSESSMENT TOOL	INTENDED USER	PURPOSE	REQUIREMENTS (TIME, EXPERTISE ETC)	COMMENTS
RAPID VALUATION PROTOCOL (**Report title:** Vol IV. A protocol for the quantification and valuation of wetlands ecosystem services. By J. Turpie and M. Kleynhans)				
Wetland valuation protocol	DWAF (Intermediate and Comprehensive Reserves), municipalities, landowners, EIA consultants.	A protocol for the rapid valuation (in monetary terms) of the benefits provided by a given wetland. To a lesser extent the change in benefits provided under alternative policy or management decisions can be valued (with low confidence).	To be led by a resource-economist who is knowledgeable about wetland functioning, working with (as necessary) a hydrologist and water quality expert. Depending on the wetland, its context, existing information and the level of confidence required, the assessment could take 2 days to 2 months	Reported in "A protocol for estimating the economic value of wetlands."
DEPENDENCY METRIC (**Report title: Vol III:** A tool for the assessment of the livelihood value of wetlands. By J. Turpie)				
A tool for assessing livelihood dependency on a wetland	Municipalities, NGOs, landowners, DWAF, other government agencies, EIA consultants.	To assess the extent to which the surrounding community depends on given wetland for their livelihoods.	Resource economist or social scientist that is knowledgeable about wetland biodiversity and functioning. The time required for the assessment will depend on the complexity of the wetland and its socio-economic and land tenure context, likely to be in the order of 1-5 days.	Reported in: "WET-Dependency: a metric for assessing community dependence on wetlands."
SUSTAINABILITY METRICS (**Report title:** WET-SustainableUse: A system for assessing the sustainability of wetland use. By D. Kotze)				
Sustainability of wetland use	Government agencies, especially Department of Agriculture, NGOs, municipalities, researchers, well-informed landowners.	To assess the ecological and social sustainability of wetland-use. Specific guidance is provided for the following uses: cultivation, livestock grazing and vegetation harvesting.	Specialist expertise requirements not high, but will require a high level of general experience in land and natural resource utilization and wetland health assessment. The time required for the assessment will depend on the complexity of the wetland and its socio-economic and land tenure context and on the number of different uses and impacts impinging on the wetland. Most assessments likely to take from 1 to 5 days, including preparation and gathering background information.	The sustainability metrics follow a similar structure and approach to WET-Health, and are designed as a "plug-in" to the WET-Health system Reported in: "WET-SustainableUse: metrics for assessing the sustainability of wetland use. A prototype."

ASSESSMENT TOOL	INTENDED USER	PURPOSE	REQUIREMENTS (TIME, EXPERTISE ETC)	COMMENTS
CUMULATIVE IMPACT OF WETLAND LOSS (**Report title:** A method for assessing cumulative impacts on wetland functions at the catchment or landscape scale. By W. Ellery *et al.*)				
CUMULATIVE IMPACT OF WETLAND LOSS	1) Working for Wetlands (planning rehabilitation) 2) Catchment Management agencies (identifying wetlands to achieve catchment scale objectives) 3) Water authorities / utilities such as Umgeni Water and Rand Water (identifying wetlands to use to achieve catchment scale objectives related mainly to water quality) 4) DWAF and Reserve determinations to identify wetlands of high functional value 5) Conservation agencies (as part of conservation planning initiatives)	A method to assess the cumulative impact of wetland loss in a catchment.	Reasonable inventory information, a classification of wetlands present into HGM types, and their spatial distribution on streams present. GIS skills are very helpful (possibly critical), although it is possible to do small areas manually.	GIS-based.

5. AN OVERVIEW OF THE WHI SERIES

5.1 List of products generated by the WHI programme

A list of the major outputs of the WHI programme was presented in Table 1.1 in terms of the three major components of the programme, namely:

- projects using biota for wetland assessment (macro- and micro- flora and fauna);
- broad-scale assessment of hydrological impact and wetland ecosystem services; and
- socio-economic and sustainability studies, including the development of resource economics and sustainability metrics.

In addition to the above components, the table also lists a number of so-called “miscellaneous products” that are not discussed in more detail in this report, but which nevertheless form part of the stipulated outputs of the overall programme.

Figure 5.1 shows a map of the sampling sites that were used by the various projects during the WHI programme. An Excel database was created to house the biological sampling data from the Western Cape and is recorded on a CD provided at the back of this document. The data were collected from mainly pans and seep wetlands over the period of 2007 to the end of 2008. Descriptions of each of the wetland sites are provided, as well as water quality data, plant and invertebrate species lists where collected. Reference photographs for each of the wetlands are also included.

The following sections provide summary information regarding each of the tools that have been developed as part of this project, with comments on the applicability of each in terms of different wetland type, socio-economic context, physical and ecological conditions, and purpose of application. The inter-relationships between different components and/or tools of the WHI programme are explored in Section 6.

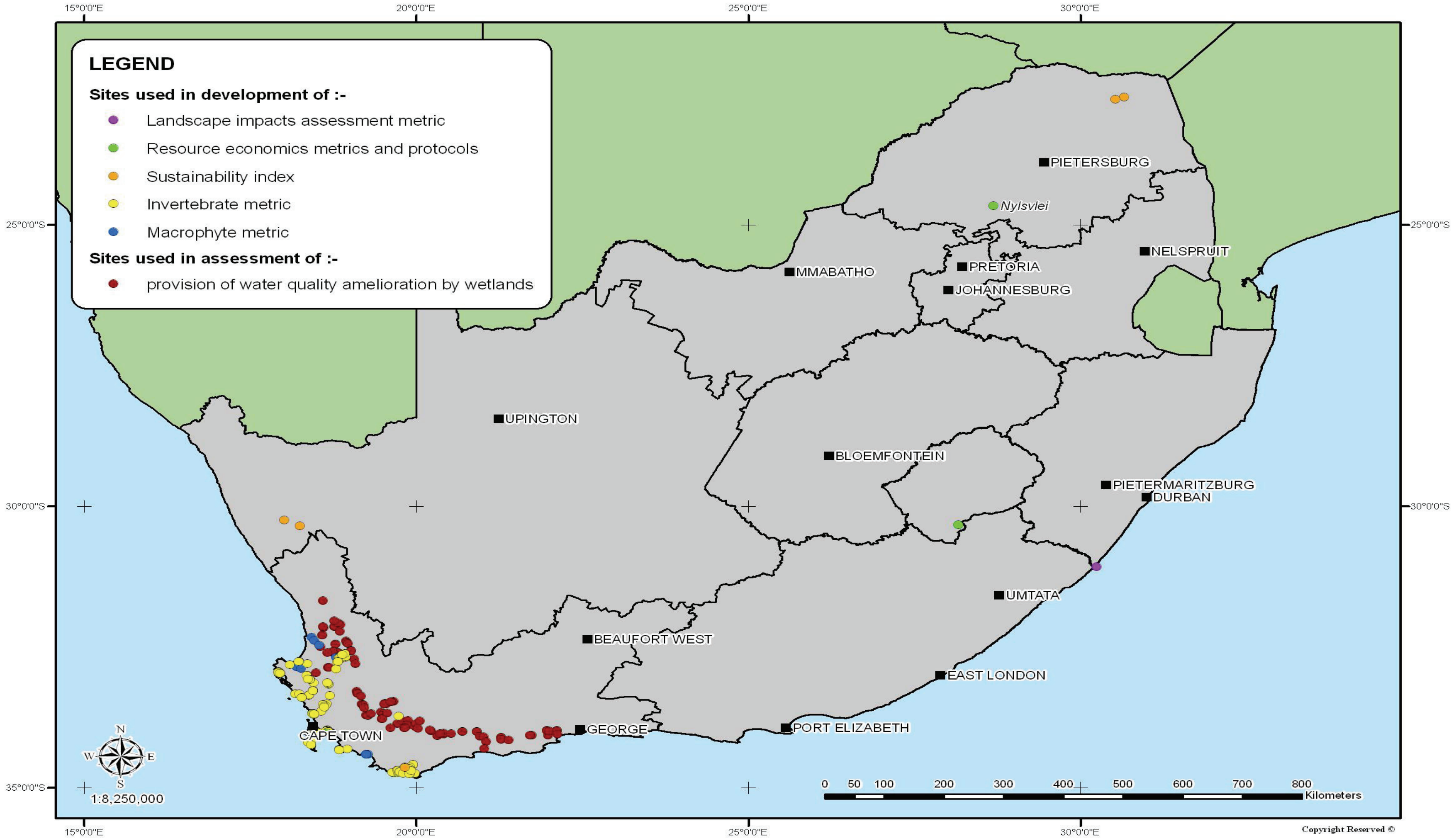

Figure 5.1: Distribution of sampling sites used by different WHI project components in the collection of data to develop and/or test indices of wetland condition, sustainability, function and/or resource dependency and value. See individual reports for details of sampling protocols and site descriptions.

5.2 The development of tools focusing on biophysical condition at a wetland scale

Three tools that focus on biotic elements have been considered and developed to various levels in the WHI programme. These comprise:

- an index based on wetland invertebrates;
- an index based on wetland macrophytes (large plants); and
- a tool for assessing cryptic wetlands in their dry condition, based on abiotic and biotic factors.

5.2.1 Aquatic invertebrates as indicators of human disturbance in South African wetlands (Bird 2010)

5.2.1.1 Aims

The objectives of this study were to:

- collate and review both local and international literature relating to wetland biological assessment using aquatic invertebrates;
- conduct an investigation into the response of aquatic invertebrates (including microcrustaceans) to anthropogenic disturbances in wetlands of the Western Cape, South Africa;
- identify candidate invertebrate taxa or metrics for assessment of wetland condition in the Western Cape region; if useful indicator taxa and/or metrics are established, to provide a protocol for assessing their applicability in other regions and wetland types of South Africa; and
- investigate the applicability of the SASS river index to wetlands.

5.2.1.2 Approach

Bird (2010) assessed the feasibility of developing an index for wetland assessment based on invertebrates (both macro- and micro-). Data were obtained from wet-season assessments of 125 wetlands in the winter rainfall region of the Western Cape (Figure 5.1). Two wetland HGM units were addressed, namely seasonal **depressions**, from slope, valley floor, plain and bench landscape settings (see Table 2.1), and **unchannelled valley bottom wetlands**. Of these, the latter were investigated at a superficial level only, with the bulk of sampling focusing on seasonal depressions i.e. that contained water only during the winter period, a wetland type that predominates in the Western Cape.

Wetlands across a gradient of anthropogenic disturbance were assessed, with wetland condition independently (but qualitatively) assessed as ranging between relatively unimpacted, moderately impacted and seriously impacted when compared to an assumed natural condition. Assessment of impact was based on the presence of visible indicators of impact at each wetland site and was assigned a “human disturbance score” (HDS). For example, the presence of an outlet into a wetland from a livestock feed area would result in nutrient enrichment in the wetland. Water chemistry and faunal data potentially provided independent correlates to these indicators of wetland impairment.

Correlational links between invertebrates and basic chemical and physical wetland attributes were tested, with the main water chemistry variables assessed being salinity (measured as electrical conductivity; EC), pH, orthophosphate, nitrite, nitrate and ammonium and total suspended solids. In addition, hydroperiod was also assessed, with dry season soil moisture content and wet season water depth both being used to provide correlational information regarding wetland hydroperiod. The approaches used to test for correlational links between land-use or water quality and invertebrate community composition and abundance included identification of indicator taxa and metrics of disturbance. Development of a multi-metric index of biotic integrity (IBI) and a SASS-type numerical index were investigated.

5.2.1.3 Major findings

<u>Seasonal depression wetlands</u>

- The **macroinvertebrate** families sampled in the study did not show clear relationships with human disturbance variables as proxied by land-use (HDS) and nutrient levels. The majority of families showed a generalist response to human disturbances and the results did not provide encouragement for establishment of an invertebrate index for this wetland type.
- The study did not find evidence from metrics or indicator species testing to suggest that **microcrustaceans** are useful for inclusion in wetland bioassessment indices in South Africa. This conclusion was reached, partly because of the laborious enumeration and identification procedures involved and partly because of the lack of

good indicator patterns observed in this study. More research in other wetland types and regions would clarify this issue.

- The riverine assessment method “SASS” (South African scoring system) *per se* is not suitable for seasonal depression wetlands (nor for unchannelled valley-bottom wetlands – see below).
- Despite relatively poor bioassessment results for seasonal depression wetlands in the Western Cape, a **prototype numerical biotic index** has been developed during this study (essentially a modification of the SASS river index), which shows potential for testing in other wetland types and regions of South Africa.
- For this assessment framework, the prescribed approach is to first use a training dataset in order to modify the tolerance scores (for the prototype numerical biotic index) according to the prevalent taxa for a given wetland type/region. This would be followed by testing of the index with an independent set of data to clarify its inferential power.
- The multimetric IBI approach, although shown to be useful in certain parts of the United States, is not recommended as a way forward for rapid wetland bioassessment in South Africa. This conclusion is reached due to a combination of factors: the need for quantitative data; the often laborious process of calculating metrics; the sometimes required identification of taxa beyond family level; and the relatively poor performance of this approach compared to the numerical biotic index as observed during this study.

<u>Valley bottom wetlands</u>

- SASS appeared unable to distinguish impairment levels reliably among sites in comparison to the precision witnessed when using this index in rivers. Thus, a certain degree of inferential power is lost when transferring SASS from rivers to valley bottom wetlands.
- A practical problem is often encountered in that the water depth is frequently too shallow in this type of wetland for the SASS sampling protocol. Bioassessment methods less reliant on surface water may prove more feasible for this wetland type.

5.2.1.4 Application to other eco-regions and other HGM units

From the literature study for this project, it was found that aquatic invertebrates are NOT a feasible tool for wetland bioassessment in areas where the influence of natural environmental disturbances outweigh anthropogenic-induced disturbances. Although macroinvertebrates found in seasonal depression wetlands of the Western Cape were found to be generalists, it is possible that those from more permanent wetland types, as found in the more mesic parts of the country may show stronger relationships with environmental variables (although preliminary results are also not promising (see Bird 2010). Thus, although not suitable for seasonal depression wetlands it *may* be suitable to other HGM types (for instance permanent depression wetlands). The hypothesis behind this is that systems in which anthropogenic disturbance is greater than natural variation will be more amenable to bioassessment. The natural variation in seasonal wetlands is very high.

Although the development of the numerical index has been based on data from winter rainfall areas in the Western Cape only, most of the taxa inhabiting assessed sites form part of the Pan-Ethiopian invertebrate fauna – a group that is considered to be quite widespread across Southern Africa (Bird 2010). Thus, extrapolation of an invertebrate index to other eco-regions within South Africa may be quite feasible.

5.2.1.5 Challenges faced by the project

One of the major problems faced by the investigator of this potential assessment tool was the dearth of any quantitative or even qualitative invertebrate data for wetlands. This means that a major part of the time and effort involved in the feasibility assessment actually focused on the collection of baseline invertebrate and water quality data. Identification of invertebrates to species level often required specialist input – sometimes from overseas specialists. Of necessity, these factors limited the number of eco-regions in which this study could take place (a single eco-region only was investigated), and also limited the number of wetland types that could be included in the assessment without compromising the collection of an adequate number of replicate invertebrate and physico-chemical samples, spanning a range of levels of anthropogenic impact. Another major challenge (and one that will face researchers wanting to extend the prototype numerical index to other wetland types and eco-regions) is the need to identify a suite of wetlands all of the same type, in the same region and showing a range of degrees of impact (from unimpacted to severely impacted). The type of impact should also preferably be the same.

5.2.2 Development of a tool for the assessment of the environmental condition of wetlands using macrophytes (Corry 2010)

5.2.2.1 Approach

International literature has established that wetland macrophyte communities are a product of causal environmental factors, including hydrological and mineral nutrient conditions; sediment fluxes, herbivory, fire and man-made disturbances, and several countries use macrophytes in the bioassessment of wetlands. To date, no index of wetland condition based on macrophytes alone has been developed for South Africa. Nevertheless, existing data suggest that South African macrophyte communities and their individual species components might usefully be used as an indicator of wetland condition, since macrophytes from similar wetland types within the same eco-region and with the same substrate are likely to respond along a gradient of impact to different levels of the same kind of anthropogenic impact. The likely responses exhibited by wetland macrophytes include differences in:

- species presence/absence, cover and abundance;
- the ratio of indigenous to invasive cover;
- the ratio of graminoid to herbaceous species; and
- changes in species diversity or other collective measures of the plant assemblage.

If there are recognizable trends within these responses that, when compared against an ascending level of human impact can be shown to increase in magnitude, then they can be identified as metrics (measures) of divergence from natural conditions. Such metrics can be collated into an index that measures the level of environmental intactness or condition relative to the reference state of an unimpacted wetland.

The following approach was taken in the development of a macrophyte index:

- a review of methodologies used for macrophyte and riparian vegetation bioassessment both internationally and in South Africa was carried out. For the local component the review focused on the Vegetation module of WET-Health (as presented in Macfarlane *et al.,* 2008) and the rapid, field-based Riparian Vegetation Response Assessment Index (VEGRAI; Kleynhans *et al.,* 2007) developed by DWAF;
- a review was then conducted of how wetland macrophytes respond to changes in ecological drivers such as hydrological regime, nutrient and sediment fluxes,

herbivory, fire and man-made disturbances, with specific reference to conditions found in South African wetlands;

- existing species lists and data (Goldblatt and Manning, 2000; Cook, 2004; Mucina *et al.,* 2006) on the distribution of obligate and facultative wetland plants in the Western Cape of South Africa were collated and a comprehensive list for the Western Cape was produced;
- floristic-sociological and environmental data from 60 wetlands in the winter rainfall area of South Africa was collected. Within these wetlands a multitude of habitat units were assessed as the hydrogeomorphic unit does not by itself distinguish units of comparable vegetation. Wetlands across a range of cumulative human disturbance were assessed. The assessment of cumulative disturbance was based upon human activities apparent within wetland and the surrounding land. This qualitative assessment of environmental condition was independent from measurement of the vegetation to avoid circular reasoning. Water and soil chemistry provided other independently assessed measurement of environmental conditions in the wetlands. The data were analyzed with multivariate means to determine potential indicator species and other attributes of the vegetation assemblage that correlated with reference or disturbed environmental conditions;
- an index of wetland environmental condition was developed for depressional wetlands in a localized area of the Cape Flats; and
- general principles were distilled and a generic protocol drawn up to enable the development of macrophyte-based indices of wetland condition for other areas of the country (and for other wetland types).

5.2.2.2 Findings

<u>Application of the WET-Health module as a rapid macrophyte bioassessment tool:</u>

The study recommends the application of the Vegetation module of WET-Health (as presented in Macfarlane *et al.,* 2008) for rapid assessment of wetland condition, based on vegetation, which yields an assessment of wetland class that is compatible with the A-E classes accorded within the RDM. Although WET-Health (specifically the Hydrology module) has been developed for floodplain and valley bottom wetlands only, the Vegetation module can be applied to other types of HGM units such as depressional wetlands.

Note that WET-Health does not include actual measurements of biota, but rather looks at factors that have changed the landscape in and around an assessed wetland. These factors include the extent of alien or weedy species (which may be terrestrial, indigenous plants). Thus the degree to which plant invasion has occurred is qualitatively measured, and/or the amount of change from the natural condition is assessed. The methodology does not assess the indigenous vegetation in detail to look for subtle change in composition or cover and abundance, relying instead on inference that percentage invasion by aliens or change from a natural state will impact on the condition of the vegetation community. Since WET-Health assesses only the extent of alien vegetation and the degree of change from natural conditions, it provides limited opportunity to assess causal factors underlying these impacts.

Application of VEGRAI as a rapid macrophyte bioassessment tool:

The rapid, river-based metric known as the Riparian Vegetation Response Assessment Index (VEGRAI) was assessed for its applicability to wetlands. A VEGRAI assessment is based largely on qualitative comparison of aspects of vegetation in a river reach to what would occur in the expected reference condition, rather than on a measured response of plants to specified stressors. In the case of many wetland types, there are no data to inform the characterization of reference conditions, and the approach thus places a heavy onus on the experience of the assessor, both in terms of determination of conditions under which a wetland is self-regulatory and in terms of derivation of expected reference conditions for a particular wetland. The paucity of biological data for many wetland types means that low confidence would usually be attached to the assignation of reference conditions to a given wetland.

Both assessment tools, VEGRAI and WET-Health, are considered potentially useful in allowing an overall, low-confidence sense of present wetland condition, relative to an assumed "natural" condition. This does assume that a good sense of the natural condition can be determined from investigation of un-impacted wetlands in the immediate vicinity of those being assessed.

5.2.2.3 Development of a Macrophyte assessment Index

The macrophyte bioassessment index under development in this component of the WHI programme is based on data collected from 60 wetlands, comprising a variety of HGM unit types, predominantly of depressional wetlands from a variety of landforms (Figure 5.1). The wetlands assessed were predominantly characterized by Cape Lowland Freshwater vegetation (*sensu* Mucina *et al.,* 2006) but other classes of wetland vegetation were included.

Assessed wetlands were separated into various classes of wetland vegetation type by assessment of the hydrological regime and habitat based on the descriptions as used by Mucina *et al.* (2006). In addition, the dominant species were also used. Those that were dominated by species considered by Mucina *et al.* (2006) to be the key species for each vegetation type were then assigned to that category of vegetation. It was found, however, that many of the wetlands had combinations of dominant species from the different wetland vegetation classes. Analyses of plant community data showed significant differences in wetland plant communities of the Cape Lowland Freshwater vegetation class in different geographical locations within the eco-regions that were studied, thus suggesting the need to develop separate metrics for bioassessment of palustrine wetlands within these different locations within each eco-region.

The metrics that have been developed focus on the responses of functional types of plants to different environmental stressors (e.g. the extent of surface cover or the number or percentage of vegetatively reproducing stress-tolerant graminoid taxa or the number of shrubs and trees). Unfortunately, the metrics are only sensitive enough to distinguish between two broad categories of disturbance i.e. disturbed or undisturbed conditions. Those wetlands with an intermediate amount of disturbance or mesotrophic systems do not show a significantly different community of vegetation to those with low levels of disturbance, and the metric is thus not sensitive from this perspective. This may be due to a lack of accuracy in discrimination between the different categories of disturbance and could potentially improve with more research.

5.2.2.4 Application to other eco-regions

The results of this project suggest that extensive modification of the proposed metrics would need to take place if a macrophyte bioassessment tool is to be extrapolated to other areas. This would require sampling of at least 30 wetland units in each area of homogenous wetland vegetation community. Measurement of sample plots of each typical assemblage of plants within each wetland will need to be collected along with soil and water quality data as well as human disturbance scores. Derivation of the homogenous units themselves is likely to be a major undertaking. This is because to date, the spatial frameworks of bioregion (Brown *et al.,* 1996), eco-region (Kleynhans, 2005), Cowan's wetland regions (1995), the bioregions of Rutherford *et al.* (2006), and wetland vegetation types of Mucina *et al.* (2006) have all proven to be too coarse a scale in terms of separating comparable spatial units of freshwater wetland vegetation. A sampling strategy and framework for extending the index to other habitat types is included in the report.

5.2.2.5 Application to other wetland HGM units

The macrophyte index approach differs substantially from that of other biotic indices in that it is not carried out at the scale of a particular HGM unit, but is rather based on the habitat descriptors of the Wetland Classification. Hence, flat sandy habitats (for example) could occur in a variety of HGM units, with wetland vegetation within this habitat type potentially being linked to descriptors such as hydroperiod rather than to specific HGM units which themselves may comprise a number of different habitat types.

5.2.2.6 Challenges faced in the development of the index

There were significant problems encountered during this project.

1. There is a lack of basic ecological information about wetland plant taxa in South Africa; for instance their distribution and association with environmental parameters, tolerance to environmental disturbance or what constitutes a natural or reference plant assemblage. Considerably less information is known than in areas of the world which have successfully developed methods of bioassessment.
2. Efforts to identify indicator species (through expert knowledge and published literature) were not fruitful. Phyto-sociological research in wetlands is in its infancy in South Africa, hence classification of wetland vegetation types and indicator species for natural environmental conditions have not been determined.
3. High plant diversity in the fynbos biome of both “wetland plants” and upland taxa encountered surrounding wetland areas suggests considerable complexity and variability in these vegetation types (more than 510 species were recorded). This involved intensive training so as to identify plants in the field.

4. The National Wetland Classification Scheme as used at the outset of the project did not include the secondary discriminators (levels 5 and 6) latterly included to differentiate between different habitat classes.
5. There is a high natural inherent variation in the underlying physico-chemical template (soil type, geology, climate etc.) in the W Cape (along with the Drakensberg, the Capensis plant region is known to be very diverse due to extreme variation of determining environmental and geographic parameters). This in part explains the high plant diversity. This variability is manifested at several scales, from regional to micro-habitat (i.e. within wetland). This challenge also provided an opportunity of being able to research many different habitats within a relatively limited geographical area, which may also be applicable to understanding plant associations to environmental conditions in wetland habitat in other geographical locations in South Africa.
6. The definition of "wetland" includes an array of habitats, resulting from different hydrological zones, which creates considerable plant diversity within the confines of a single wetland. These different habitats and the plants that occur within them are linked by the hydrological regime and the soils at a given site. The human stressors that change plant distribution do not act evenly across all of the habitats and it unclear in which habitat to sample in order to pick up the impacts of these stressors. It is therefore necessary to sample the full array of habitats and assemblages of species in every wetland which can be very labour-intensive.
7. To develop an index, one needs to study the plant communities in similar habitats that differ only in the magnitude of the amount of human disturbance that has altered the wetland environmental condition. There are several different stressors (types of impact) that wetlands are subject to, and usually wetlands will be subject to multiple stressors. The reality is that it is very difficult to find a group of wetlands in the same geographical region, of the same wetland (HGM) type, that are only subject to one type of impact.
8. The development of bioassessment indices is an iterative process as evidenced by the number of revisions and updates to reports emanating from the organizations charged with this responsibility in the United States Environmental Protection Agency. Considerable time and personnel are assigned to developing bioassessment protocols in the United States. Whilst considerable input was been solicited from wetland ecologists in South Africa there is very limited knowledge directly relating to this field of expertise.

5.2.3 Assessment of temporary wetlands during dry conditions

5.2.3.1 Approach

This component of the WHI programme did not result in the development of specific metrics allowing measurement of the degree of wetland impairment. Instead, it rather focused on the isolation of a number of indicators of particular wetland characteristics, from which, assuming some understanding of reference condition characteristics, predictions as to likely wetland function and degree of impairment can be made. The tool focused on the kinds of indicators that are likely to be available for measurement or observation during the dry season, thus enabling limited levels of wetland assessment to take place outside of natural inundation cycles for seasonal and particularly cryptic wetlands. "Cryptic" wetlands are temporary wetlands which cannot reliably be identified as wetlands during the dry season on the basis of standard wetland identification and delineation tools (i.e. using soils).

Development of this tool was based on assessment of wet season water quality and invertebrate data, correlated with the results of artificial incubation of soil samples collected from seasonally inundated wetlands in the dry season. Data were collected from depressional wetlands only, within the winter rainfall area of the Western Cape (Figure 5.1).

5.2.3.2 Findings

Table 5.1 lists indicators available during the dry condition that are useful for assessment of cryptic and seasonal wetlands. It summarises specific information that their presence, and sometimes their absence, can indicate about wetland type, character and function. Based on the information provided in the table, a number of conclusions can be drawn about the use of these indicators in assessment of temporary and other cryptic wetlands during their dry season.

- No single indicator provides adequate information about wetland presence, type, hydroperiod, biodiversity, function and principle ecological and hydrological drivers to be useful on its own. In fact, with regard to actual or suspected cryptic and/or temporary wetlands, assessment of a suite of indicators is required to build up even a conceptual understanding of wetland ecosystem structure and function
- The absence of an indicator does not necessarily equate to the absence of a wetland.

- The confidence associated with linking specific chemical, physical or hydrological conditions to each indicator is almost invariably low. The level of confidence can be improved substantially by corroboration with a number of other indicators.
- Indicators substantiating the existence of a wetland may be associated with a higher level of confidence than interpretation of indicators of wetland character (e.g. seasonally inundated or seasonally saturated) and /or biodiversity.
- Seasonally / ephemerally *inundated* wetlands are identifiable to a higher level of confidence than seasonally *saturated* systems, as a result of specific indicators for these conditions (e.g. algae and the presence of aquatic invertebrate communities).
- Detailed delineation of cryptic wetlands is unlikely to be achievable with any useful degree of confidence based on a dry season assessment only, although landform might be used in conjunction with other indicators to produce approximate estimates of wetland extent.
- Water chemistry (e.g. nutrient concentrations and loading) is not easy to assess on the basis of dry season assessments, unless substantial macrophyte or algal material persist into the dry season.
- Although some links have been made between crustacean taxa and various water qualities, hydrological and physical aspects, these require further investigation under controlled conditions, and are based at present on broad correlational data only.
- Hydroperiod appears to be reflected most accurately by aquatic invertebrate communities – although such an approach would be applicable for seasonally inundated systems only.
- Subtleties in hydroperiod appear to be of great importance in determining wetland crustacean community structure and hence are of biodiversity significance. The extent to which wetland soils actually dry out in the dry season apparently has the capacity to affect invertebrate ecosystem structure, and an assessment of this variable allows estimates of trajectories of wetland change to be made, particularly with respect to changes in hydroperiod.

5.2.3.3 Further development

The assessment tool developed in this project focused on measurements of wetland structure. Based on these, coarse estimates of function can be made. Once such estimates have been informed by even a conceptual understanding of the major drivers and threshold conditions determining present wetland structure, other assessment protocols may be more easily applicable to the assessment of these systems. In particular, assessment tools such as WET-EcoServices (Kotze *et al.,* 2008a) and WET-Health (Macfarlane *et al.,* 2008) are considered complementary to the dry season assessment strategy, which is essentially an enabling device to improve conceptual understanding of wetlands to a point where other metrics may reasonably be applied.

5.2.3.4 Extrapolation to other eco-regions?

The faunal component of the dry season assessment protocol would also require the collection of baseline data in other eco-regions, although the abiotic components are considered to be robust between eco-regions.

Table 5.1: Summary of major physical, chemical and biological indicators available for assessment during the dry season and providing information on particular aspects of wetland condition

Indicator	Condition indicated	Complementary indicators	Confidence
Biotic indicators			
Invertebrates			
Invertebrates hatched out from dry season sediments under laboratory conditions			
Overall invertebrate assemblage	Crustacean assemblage a surrogate for wet season component – can show expanded faunal component, including sequential colonization effects; insect and other invertebrate components unlikely to be represented in dry season sediment samples. If site known to include wetlands but crustacean component absent from hatched samples – then either hydroperiod is too long or wetland not seasonally inundated, but rather saturated Presence of aquatic invertebrates indicates wetland now or in past subject to seasonal inundation This may be the only indicator of small, cryptic wetlands on rocky substrata with no plants and virtually no soil.	Dry season soil moisture Presence of shells/ exoskeletons of aquatic invertebrates	High
Crustacean component			
Anostraca	Abundant when dry season soils very dry (<6%) Potentially intolerant of high free ammonia concentrations (>0.1mg/L), high EC (>900 mS/m), summer moisture	Soil moisture Abiotic indicators	Low – data correlative only
Conchostraca	Abundant when dry season soils very dry (<6%) Absent when dry season soils >30 % moisture		
Cladocera	Abundant when dry season soils very dry (<30%) Tolerant of wide range of nutrient availability, turbidity and EC		
Ostracoda	Abundant when dry season soils very dry (<30%) Tolerant of wide range of nutrient availability, turbidity and EC		
Copepoda	Abundant when dry season soils very dry (<30%) Tolerant of wide range of nutrient availability, turbidity and EC		
Presence of old cases, exoskeletons,	Indicative that periodic inundation of the site has taken place in the past – not reliable indicator of present hydroperiod unless other	Abiotic and invertebrate	Low

Indicator	Condition indicated	Complementary indicators	Confidence
shells of aquatic invertebrates in sediments	factors present	indicators	
Macrophytes			
Presence of perennial or annual hydrophytes – growing or clearly identifiable dried plant remnants during the dry season	Wetland conditions definitely present – plant species habitat requirements (e.g. inundation etc.) will determine wetland type (e.g. seasonally inundated) and (low confidence) range of habitats	Invertebrate and abiotic indicators	High
Presence of facultative wetland species	Wetlands may be present – in drier climates, presence of facultative wetland species has a higher likelihood of being linked to wetland conditions	Invertebrate and abiotic indicators	Low to medium
Absence of both dryland and wetland plants from site	Presence of a wetland cannot be ruled out on this basis alone; in absence of invertebrate, soil or other markers, presence of seasonally inundated wetland unlikely, but small wetlands in rocky substrata may have none of these	Signs of recent fire? Abiotic indicators Invertebrate indicators	Low
Presence of halophytes	Indicate saline soils in and around wetlands – but may also indicate non-wetland saline soils, especially in mesic areas	Other abiotic and/or biotic indicators essential	Low
Algae			
Algae developing in incubated samples	May simply represent opportunistic propagation of air-borne spores – identification to genus / species level may improve confidence	Abiotic and biotic indicators	Low
Presence of dried algal remnants	Indicative of wet season water levels – indicates seasonal / periodic inundation	Soil moisture Invertebrates	High
Abiotic indicators			
Topography	Indicates potential for accumulation of water in wet season – must be interpreted with other indicators	Abiotic and biotic	Low
Soil wetness	Presence of gleying, mottling: if present as per DWAF (2005) then indicates wetland type (permanent / seasonal etc.) Absence of above, coupled with sandy soil, and/or arid climate and/or perched wetland conditions: cryptic wetland cannot be ruled out Dry season soil moisture data:	Biotic and abiotic	High

Indicator	Condition indicated	Complementary indicators	Confidence
	>30% and presence of other indicators of wetland conditions: wetland may not support crustacean fauna; lower species diversity <30% and presence of other indicators of wetland conditions: wetland may support crustacean fauna and potentially linked to higher species diversity / endemism		Low
	Dry season water table <0.5m from surface OR impermeable layer <0.5m from surface: indicates wetland presence but not hydroperiod (inundated or not) Dry season water table >0.5m from surface OR impermeable layer >0.5m from surface: no strong conclusions can be drawn	Biotic and abiotic – including soil moisture	Medium Low
Muck layer	Thin layer (<2cm deep): Presence: wetland conditions in recent past / present Absence: inconclusive Thick layer (<2cm deep): wetland conditions in past		Medium Medium
Sediment deposits on plants and/or rocks	Presence: indicates minimum levels of inundation – wetland assumed to be seasonally inundated Absence: inconclusive		Medium Low
Biotic crusts	Presence: indicates minimum levels of inundation – wetland assumed to be seasonally inundated Absence: inconclusive		High Low
Water marks	Presence: indicates minimum levels of inundation – wetland assumed to be seasonally inundated Absence: inconclusive		Medium Low

5.3 Broad-scale assessment of hydrological impact and wetland ecosystem services

This work is reported in “Assessing cumulative impacts on wetland functions at the catchment or landscape scale” (Ellery *et al.* 2010).

5.3.1 Aims and approach used

The overall aim of this study was to develop a method that allows for assessment of the provision of ecosystem services at a catchment or landscape scale based on impacts of human activity on wetland hydrological health. This approach is used, since the hydrological regime is the most important determinant of wetland structure and function (Mitsch and Gosselink, 2007). The specific objectives of this study were to:

- develop a measure that describes the impact of land cover change as mapped nationally in National Land Cover datasets on wetland hydrological health in the form of a **land cover change impact metric**,
- relate wetland hydrological health to the provision of a given ecosystem service in the form of a **loss of function metric**,
- integrate the land cover change impact metric and the loss of function metric to produce a **functional effectiveness score**,
- develop an approach for meaningfully translating the functional effectiveness score on an area-weighted basis as **functional hectare equivalents** for a range of ecosystem services; and
- scale up the consequences of human activities on the provision of ecosystem services, from an individual wetland to a catchment or landscape scale such that many wetlands can be considered jointly and **cumulative impacts** can be assessed.

The relationship between these objectives (and components) is depicted in Figure 5.2.

Different land-uses covered in the National Land Cover database for South Africa were examined and categorised according to the likely impact on hydrology. The various Land cover classes (31 in total) were grouped into categories (12) based on likely impacts on water inputs to, and retention of, water within wetlands. If present in the catchment, these land cover categories can either 1) increase or 2) decrease water inputs to a wetland. If present in a wetland itself, they can 3) increase direct water losses from the wetland, 4) reduce surface roughness, 5) impede the flow of water in a wetland or 6) enhance the flow of water out of a wetland. The effect of each category of land cover change from the natural condition on each of these parameters has been assigned an intensity of impact score.

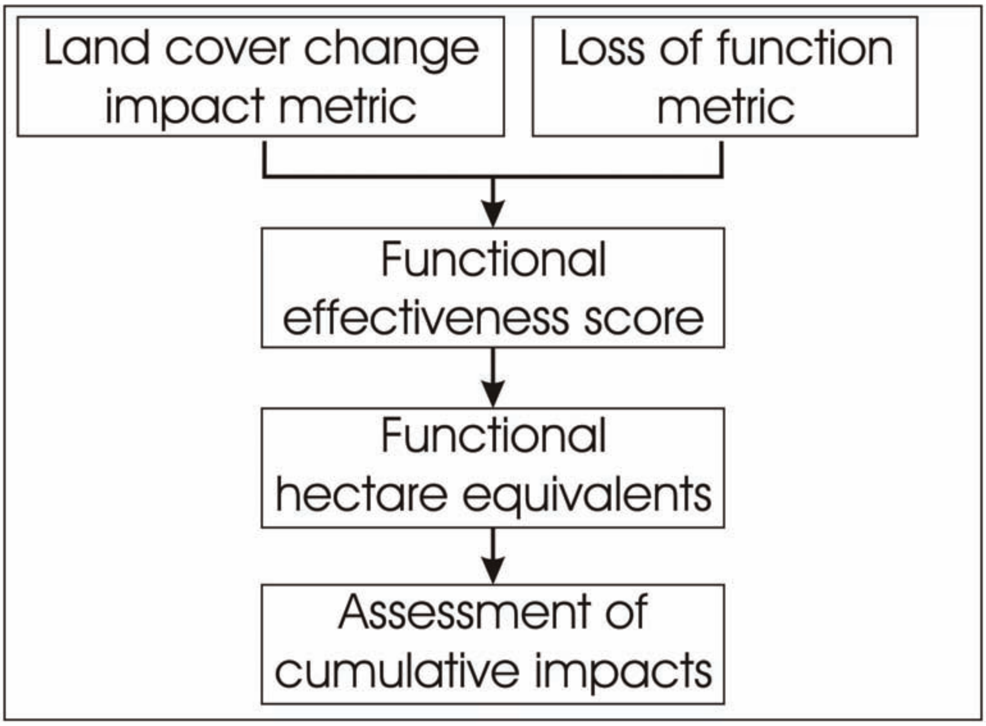

Figure 5.2: Summary of the relationships between different components of the cumulative impact study.

The method considers the impact of land cover change on wetland health using a **land cover change impact metric**. This metric is based on the recognition that wetland structure and function are fundamentally affected by the hydrological regime. The land cover change impact metric requires that the extent of each land cover category is determined as a proportion of the catchment and wetland area, and that this is multiplied by the intensity of impact score, to produce a magnitude of impact score.

The manner of entry into and pattern of water flow through a wetland affects the extent to which a wetland is able to deliver particular ecosystem services. Therefore, for purposes of this assessment, floodplain wetlands have been distinguished from valley-bottom wetlands. For wetlands other than these two hydrogeomorphic types, the method applicable to valley-bottom wetlands should be used.

A second metric, the **loss of function metric**, describes the relationship between the magnitude of impact score and wetland functionality for a total of six ecosystem services: A) flood attenuation, B) streamflow regulation, C) sediment trapping, D) nitrogen removal,

E) phosphate removal or F) toxicant removal. These relationships have been developed based on limited field testing, and there is a need to verify their applicability.

The land cover change impact metric and the loss of function metric are combined in a structured way to produce a functional effectiveness score for each ecosystem service. When scaled for the area of each wetland, the functional hectare equivalents for each wetland function can be calculated, which, when compared to the functional hectare equivalents of an un-impacted catchment, is translated to an assessment of cumulative impacts.

5.3.2 Findings and applicability to different regions

This project represented the development of conceptual models (loss of function metric) linking wetland health to the level of delivery of a given ecosystem service. The models were based on data from a set of floodplains and unchannelled valley-bottom wetlands with varying degrees of impact in order to establish the relationships between impacts and the provision of each of the ecosystem services being investigated. By plotting the variation in the provision of ecosystem services in relation to wetland health it was possible to broadly understand the major factors determining variation in the provision of ecosystem services as wetland environmental condition changed. More importantly, this exercise provided an indication of the level of provision of all ecosystem services in an un-impacted state. Further work is required to verify the loss of function metrics for different HGM types, in different regions of the country and for different types of hydrological impact.

The types of hydrological impacts that wetlands are subjected to throughout the country are captured in six impact types covered in this method. Furthermore, given that this approach is based on broad physico-chemical responses that tend to be universal in wetlands of the same type, the method is likely to be applicable throughout the country. As noted above, however, it does need to be trialled further.

5.4 Tools focusing on socio-economic conditions and sustainable wetland use

5.4.1 Protocol for determining the socio-economic value of wetland ecosystem services

5.4.1.1 Approach

Turpie and Kleynhans (2010) have developed a protocol for determining the socio-economic value (i.e. monetary value) of wetlands. The approach used is based on the purpose or type of decision being made, the scale of the problem, and the time and financial resources available. The tools are aimed at facilitating an understanding amongst planners and decision makers of the potential use of wetland valuation in a variety of decision-making contexts, as well as at guiding resource economists in their understanding of the purpose and trade-offs in valuation studies, the choice of their detailed methodological approach and the role of biophysical specialists in wetland valuation.

The tools are not intended to offer a short-cut tool for rapid valuation by non-professionals.

5.4.1.2 Application of the tools

The kinds of processes for which the valuation of wetland ecosystem services would be appropriate include:

- input into conservation lobbying;
- inputs into conservation and development planning;
- designing wetland management, rehabilitation and conservation finance and incentive mechanisms;
- inputs into water resource allocation and determination of the “ecological” reserve;
- inputs into management plans, providing information around the implications of various management tradeoffs; and
- appraisal of development applications and strategic environmental assessments; and
- natural resource auditing.

The protocol relies on both existing tools and a set of methodological protocols for the quantification and valuation of wetland ecosystem services. Depending on the purpose for which the valuation is intended, and the scale of the assessment, it includes guidelines regarding the required scope, extent and methodological rigour with which the valuation should be carried out, acknowledging the inevitability of tradeoffs between confidence in the findings of an evaluation and the scope of the study.

The valuation protocol proposes three levels for the valuation of wetland services, namely comprehensive, intermediate and rapid, which can be carried out at local, catchment/ regional or national scales. The methods required, to quantify and value key wetland services at different levels of comprehensiveness and different spatial scales, are presented. Thus, once the scope and extent have been decided (i.e. which services and beneficiaries are to be considered and how values are to be expressed), this section provides a guide to design the methodological approach for each. Standard valuation methods such as Travel Cost Method and Contingent Valuation method are reviewed in a companion report (Volume I. Wetland ecosystem services and their valuation: a review of current understanding and practice. Turpie *et al.* 2010). Guidelines are provided for the valuation of the following services:

- provision of natural resources;
- flow regulation (flood attenuation, base flow maintenance);
- water treatment (water quality amelioration);
- recreational and tourism resources;
- scientific and educational value; and
- intangible (cultural, spiritual and existence) values.

The protocols differ in terms of their complexity, the kinds of data required and the confidence with which final valuations are accorded each component. The first three components depend heavily on the accuracy of biophysical and hydrological data for affected wetlands / catchments, while the last three depend on socio-economic data, and the outcome of household or local community surveys.

5.4.1.3 Application to different eco-regions and wetland types

The protocol is broadly applicable to different eco-regions, although clearly regional differences may exist in the kinds of resources offered by different wetland types across different eco-regions and in the different socio-economic context.

5.4.1.4 Links with other assessment tools

The valuation protocol is essentially a toolbox of various assessment tools that contribute to a structured valuation of specific wetland ecosystems services. Clearly, an understanding of wetland environmental condition, the range of ecosystem services it actually provides, and the sustainability of present use of the wetland are all important aspects about which the evaluator should have a clear understanding at the outset of the study. Thus the following wetland assessment tools should be considered useful precursors to application of the wetland valuation tool:

- WET-EcoServices (Kotze *et al.,* 2008a) – to identify the most important ecosystem services likely to be provided by the wetland;
- WET-Health (Macfarlane *et al.,* 2008) – to establish the environmental condition in terms of hydrology, geomorphology and vegetation;
- Wetland Livelihood Value Index (Turpie, 2010a) – to establish the dependence of the surrounding community on the wetland for their livelihoods;
- WET-SustainableUse (Kotze, 2010) – to determine the sustainability of use of the wetland by the community); and possibly
- The **land cover change impact metric** and the **Loss of function metric** as part of assessing cumulative impacts on wetland functions at the catchment or landscape scale (Ellery *et al.,* 2010) – for use in cases where a large number of wetlands, i.e. at the catchment level, need to be investigated.

5.4.2 Assessing the livelihood dependency of human communities on a wetland: The Wetland Livelihood Value Index

5.4.2.1 Aim

This index, outlined fully in Turpie (2010a) is intended to provide a relatively simple tool for the assessment of a wetland's importance to people's livelihoods, by facilitating an understanding of the level of dependence of surrounding communities on the wetland. It can be used to assess the relative importance of a particular wetland compared to others (in terms of their importance in supporting the subsistence-use of communities) in the catchment or even nationally, and to rank, or prioritise, different wetlands in terms of management priorities.

5.4.2.2 Approach

The index recognises that local communities can benefit from wetland provisioning, regulating and cultural services. The benefits accrued to communities from these services can be divided into six categories, which relate to how wetlands affect household income (through cash income, indirect and direct cost savings, indirect contributions to household income, income smoothing through risk spreading and their role in providing an income safety-net during temporary periods of economic hardship).

Factors affecting the provisioning value of wetlands in terms of these benefits include the demand for and supply of natural resources, access rights to wetlands/natural resources and the sustainability of use. Dependence on wetlands is assessed in terms of the contribution made by the wetland to reducing the vulnerability of households to poverty. This also takes cognizance of alternative resources available to households (livelihood assets). The actual wetlands Livelihood Value Index is based on the assumption that the level of dependence by households on wetlands is likely to be a function of the amount of benefit obtained and the vulnerability of the community in question.

5.4.2.3 Outline of the metric

A **Wetland Dependence Score** is computed, which describes the community's relationship with the wetland and is specific to the surrounding *community*, not the wetland. The Wetland Dependence Score has two components to in order to ascertain the level of dependence of surrounding communities on wetlands: one component to assess the benefits derived from wetlands by the local community, and another component to assess the vulnerability of that community to poverty. The **Wetland Livelihood Value Index (WLVI)** is computed based on this score and the relative size of the wetland and its surrounding community. In other words, the WLVI is specific to one or more *wetlands*, rather than any particular community. Both aspects – the Wetland Dependence score and the WLVI may be useful for different applications depending on where the focus of the study lies.

This assessment can be carried out at a desktop or comprehensive level, depending on the requirements of individual assessments. Turpie (2010a) notes however that desk-top level assessments would only be appropriate where the scope of work is so broad as to make site-visits to individual wetlands unviable.

5.4.2.4 Application to other eco-regions

The index is expected to be applicable in most developing-country contexts and would not change with eco-region.

5.4.2.5 Application to different wetland types

This index does not differentiate between different wetland types, although the types of resources found in different wetland types might in fact differ. This would be reflected in different levels of dependency. Turpie (2010a) in fact notes that the index could be developed for other non-wetland habitat types.

5.4.2.6 Links with other complementary tools

There are strong links between the WLVI and WET-SustainableUse, since WET-SustainableUse assesses the ecological sustainability of use of a particular wetland (see section 5.4.3 below). Thus it is recommended that both tools be used in order to obtain a more in-depth understanding of the situation.

Other tools that would contribute along with WET-SustainableUse to an understanding of wetland condition, trajectory of change and ecological sustainability include:

- WET-Health, which guides the rapid assessment of a wetland's ecological health based on a site visit
- WET-EcoServices, which identifies which ecosystem services are important and need to be considered in the management of a wetland or in land-use decision processes

5.4.3 Assessing the sustainability of use of wetlands: WET-SustainableUse (Kotze 2010)

5.4.3.1 Aims of the metric

WET-SustainableUse was developed to assess the ecological sustainability of wetland use, by posing questions as to what extent the use of a wetland has altered a number of key components of its environmental condition.

5.4.3.2 Approach

The development and underlying assumptions of this metric are provided in Kotze (2010). The metric is based on the precept that utilization of a resource has the potential to impact negatively on the sustained supply of that resource as well as impacting on other goods and services supplied by the wetland. This is particularly relevant in the case of uses (notably, cultivation) that involve large-scale transformation of the wetland. The primary motivation behind this metric is to assist with the assessment of the environmental sustainability of wetland use; however some consideration of social sustainability is also included. The metric focuses on:

- grazing of wetlands by livestock;
- cultivation of wetlands; and

- harvesting of wetland plants for crafts and construction.

These three uses are considered the most important uses of wetlands by local communities in South Africa. Other wetland resources that are widely used include medicinal plants, fish, wood and water itself, none of which are addressed in this assessment. Indirect uses of wetlands such as in flood attenuation and for amelioration (planned or unplanned) of water quality are not addressed either.

The metric does not prescribe what is considered sustainable use, but provides guidelines for assessing sustainability based on the particular catchment, landscape and socio-economic context of the wetland in question. Sustainable use (of wetlands) has been defined (after Ramsar, 2006) as "the maintenance of [wetland] ecological character (environmental condition), achieved through the implementation of ecosystem approaches, within the context of sustainable development", noting that sustainable use of a specific natural resource requires that use be within the resource's capacity to renew itself, i.e. it should not be beyond the resource's biological limits.

5.4.3.3 Outline of the metric

The ecological sustainability of a particular wetland use is assessed through scoring the impact of that use on the following components of the wetland's environmental condition:

- retention and distribution of water;
- retention of sediment (and its loss due to erosion);
- storage of Soil Organic Matter;
- retention and cycling of nutrients (and other elements); and
- maintenance of the native vegetation composition (diversity).

Two levels of assessment of the sustainability of a particular use are provided, depending on the level of detail required by the metric user. Level 1 is less detailed and rests upon several generalizations regarding each of the land-uses considered. Level 2 comprises a more detailed approach, and is derived largely from WET-Health (Macfarlane *et al.,* 2008). Each of the five ecological components listed above, is addressed within a set of metrics combined in a simple algorithm to represent how that component is affected by use, with the scores of individual metrics being combined into a single score to provide an overall index of the intensity of impact on the particular component. The extent and intensity are then combined to determine an overall *magnitude* of impact, with scores ranging from 0 (no impact) to 10 (critical impact). These algorithms are designed to generate an index that reflects the extent of departure from the reference un-impacted condition.

The metric also provides a mechanism for assessing the consequences of an alteration in wetland condition (resulting from use) on local wetland users and other stakeholders. This assessment is based on the following qualitative generalisations:

- reduced distribution and retention of water in the wetland often results in greater opportunities for cultivation in wetland areas, but it impacts negatively on water supply, growth of plants for craft production, and on cultivation during dry periods (when drains may prevent the storage of water in the wetland);
- erosion in the wetland impacts negatively on wetland productivity, which in turn impacts on most provisioning services and on water quality for downstream water users;
- increased breakdown of SOM may result in short term benefits for crop production as the breakdown of SOM releases nutrients for crops. However, in the long term the impacts are negative, resulting in reduced nutrient retention and soil water holding capacities;
- reduced retention of, and internal cycling of, nutrients in the wetland results in (a) reduced wetland productivity, which in turn will impact negatively on the supply of provisioning services (including cultivated food) and (b) reduced water quality for downstream areas; and
- a loss of native plant species generally reduces the resource base for medicine, crafts and thatching and livestock grazing, although the opportunistic species that replace the lost species may also have some resource value.

5.4.3.4 Application to other eco-regions

A prototype of WET-SustainableUse was refined by soliciting comment from practitioners and experts, and by applying it to several different wetland sites across four biomes, including wetlands in the Mutale catchment (Limpopo Province), Kamiesberg (Northern Cape), Agulhas plain (Western Cape) and the Dwangwa catchment (Malawi). Certain aspects of the metric may differ between biomes – the impacts of grazing, for example, while poorly understood, are considered likely to differ between biomes, and require further research.

5.4.3.5 Scale of application of this tool

The WET-SustainableUse metric has been developed with the primary focus of assessing sustainability of use at the level of an individual wetland.

5.4.3.6 Other complementary tools

Other tools that provide useful links with the concepts and outcomes of WET-SustainableUse include (in the "WET-Management series"):

- WET-EcoServices (Kotze *et al.,* 2008a);
- WET-Health (Macfarlane *et al.,* 2008);
- WET-EffectiveManage (Kotze and Breen, 2008); and
- WET-RehabPlan (Kotze *et al.,* 2008b).

From the Wetland Health and Importance (WHI) research programme:

- Wetland Livelihood Value Index (Turpie, 2010a); and
- The "land cover change impact metric" and "loss of function metric" (Ellery *et al.,* 2010).

6. CONSOLIDATING THE INTER-RELATIONSHIPS AND APPLICATION OF THE DIFFERENT WHI ASSESSMENT METRICS AND TOOLS

6.1 Summary of different applications and assessment objectives

Table 6.1 summarises the array of different tools that have been developed during the course of the WHI programme, and which variously assess aspects of wetland condition or importance, at local and catchment, or landscape scales, wetland type and function, wetland socio-economic value and the sustainability of human use of wetlands. The table includes brief notes on the main thrusts of each tool and the nature of its outputs (scores, values or simple descriptors). The major purpose and requirements in terms of time and expertise of each tool or metric have already been summarised in Table 4.1 (Section 4).

A total of eight tools have been developed during the course of the programme. Although the use of wetland invertebrates as a bioassessment tool was not found to be particularly useful in this programme (section 5.2.1), further work needs to be done to test this in more perennial systems, and thus it is included in Table 6.1. As the following sections highlight, many of these can be used in a complementary manner with both new and existing assessment tools, and some are considered essential informants of others.

6.2 Application of specific wetland assessment tools to different wetland types

Of the array of assessment tools that have been developed as part of the current programme, it is not surprising that tools that have a strong biophysical component are specific to certain wetland types only, while the tools that have a stronger social basis have a broader application across wetland types. In particular, the invertebrate study has assessed only invertebrate communities in seasonal depressional wetlands, across all Level 3 landscape settings except that of “slope”, in which depressional wetlands do not occur (see Table 2.1). The macrophyte index has a wider application across wetland HGM units, since the unit of assessment is not at the scale of a particular HGM unit, but is rather based on the habitat descriptors such as hydroperiod (level 5 of the Wetland Classification). The dry-season assessment protocol for cryptic wetlands is essentially limited to depressional wetlands, largely because these are the main type of seasonally to episodically-inundated HGM units in which this habitat type occurs.

Other metrics that are based on WET-EcoServices (e.g. the land cover change and loss of function metrics) are limited primarily to the wetland HGM units incorporated in this metric – namely, valley bottom and floodplain wetlands. Although the protocol for the quantification and valuation of wetland ecosystem services is in theory applicable across all wetland types (and the authors state that other HGM types should be “treated as valley bottom wetlands”), testing of the delivery of services such as water quality amelioration suggested that fine-tuning of this approach based on endorheic wetlands (i.e. linked to channels) would probably improve its accuracy (Turpie 2010b).

The tools focusing on socio-economic conditions and sustainable wetland use are both applicable across all wetland types, since their focus is on human behaviour and values, rather than on the attributes of specific wetland types.

Table 6.1: Summary of the major aims and linkages between wetland assessment protocols developed as part of the WHI programme

Metric name	Major thrust / aims	Application to specific HGM units	Assessment scale	Transferability between eco-regions	Complementary indices
Tools for the assessment of wetland biota					
Invertebrate Index	Assessment of impacts to water quality and wetland habitat quality and integrity, based on aquatic invertebrate communities	Seasonally or perennially inundated wetland depressions or flats	Wetland – habitat unit	Would need detailed development and testing to see if useful.	Dry season wetland assessment protocol Wet-EcoServices Wet-Health Macrophyte index Diatom index – under development in terms of WRC Project K5/1707
Macrophyte Index	Assessment of wetland condition based on macrophytes	Varied	Wetland	Needs detailed development and testing	Wet-EcoServices Wet-Health Dry season wetland assessment protocol Invertebrate index Diatom index
Protocol for the assessment of wetlands in their dry season	Assessment of wetland type, from which assumptions regarding changes from natural condition	Seasonally inundated to saturated cryptic wetlands	Wetland – habitat unit	Transferable in concept between eco-regions – but baseline data required in terms of specific invertebrate	Wet-EcoServices Macrophyte Index Diatom Index Invertebrate Index

Metric name	Major thrust / aims	Application to specific HGM units	Assessment scale	Transferability between eco-regions	Complementary indices
	can be deduced – abiotic and biotic indicators included			assemblages in cryptic wetlands	
Broad scale assessments of wetland ecosystem services, carried out at a landscape level					
Land cover change metric	Assessment of the (cumulative) impacts associated with changes in land cover on wetland hydrological "health" or integrity	Valley bottom and floodplain wetlands	Wetland to catchment	Transferable between eco-regions	WET-Health WET-EcoServices Protocol for the quantification and valuation of wetland ecosystem services
Tools that examine the delivery of goods and services by wetlands					
Loss of function metric	Assessment of changes in provision of ecosystem services as a result of human impacts on wetland hydrology	Valley bottom and floodplain wetlands	Wetland	Transferable between eco-regions	Protocol for the quantification and valuation of wetland ecosystem services WET-EcoServices WET-Health
Protocol for the quantification and valuation of wetland ecosystem services	determining the socio-economic value of wetlands, based on the purpose or type of decision being made, the scale of the problem, and the time and financial resources available	All wetland types	Wetland	Transferable between eco-regions	WET-EcoServices WET-Health Wetland Livelihood Value Index WET-SustainableUse.
Tools focusing on Socio-Economic conditions and sustainable wetland use					
Wetland Livelihood Value Index	Assessment of a wetland's importance to people's	All wetland types	Wetland	Transferable between eco-regions	WET-SustainableUse WET-Health Wet-EcoServices

Metric name	Major thrust / aims	Application to specific HGM units	Assessment scale	Transferability between eco-regions	Complementary indices
	livelihoods				
WET-SustainableUse	Assessment of the ecological sustainability of wetland use,	All wetland types	Wetland	Eco-regional differences likely –for some variables	WET-EcoServices WET-Health WET-EffectiveManage Loss of function metric Land cover change metric Wetland Livelihood Value Index WET-Rehabilitate

6.3 Application of wetland assessment tools across eco-regions

Similar issues apply in the consideration of the applicability of different assessment tools developed here, across different eco-regions. Again, those tools that have a greater reliance on biophysical data are inevitably likely to require more detailed consideration of eco-regional variation, since eco-regions themselves are set on the basis of the kinds of criteria likely to influence biodiversity. The paucity of baseline faunal, floral and water chemistry data for wetlands on even a regional basis meant that such data had to be collected before any attempts to develop assessment metrics or even protocols could be developed and thus largely limited biotic assessment protocols to the eco-regions in which they were developed. Of the three biotic tools that have been considered in the WHI series, both the invertebrate and the macrophyte components require detailed development and testing in other eco-regions before any application outside of the wet winter rainfall area can be considered. The faunal component of the dry season assessment protocol would also require the collection of baseline data in other eco-regions, although the abiotic components are considered to be robust between eco-regions.

Of the remaining assessment tools, only WET-SustainableUse is likely to require eco-regional fine-tuning – this being because of likely differences in variables such as plant-grazer responses in different eco-regions.

6.4 Suitability of different wetland assessment metrics and/or tools for different user groups

A request from potential user groups at the outset of the programme (see Section 3) was that the WHI tools should preferably:

- require no more than 3 to 4 hours of time, including site assessment, completion of datasheets and site write-up, and
- be useable by a trained technician – that is, it should not depend on interpretation by a specialist wetland practitioner.

In practice, none of the protocols developed in the WHI programme are likely to fit these criteria. Specialist practitioners with expertise in wetland invertebrates, wetland flora and wetland ecosystem structure and function are required for all of the biotic indices – this is particularly true at present, when the limitations in adequate baseline data for wetlands even within the eco-regions for which protocols have been developed, still place a heavy onus on interpretation by the assessor.

Similarly, the level of interpretation of wetland trajectory and function required in assessments of wetlands at a landscape level, and in terms of the valuation of wetland ecosystem services and the sustainability of wetland use, all require that assessors have a thorough and expert understanding of wetland processes, and thus are all likely to require specialist rather than technical input. In the case of the economic evaluations, a basic understanding of environmental economics is also required, along with a detailed understanding of the interactions between local (and other) human communities and wetland ecosystems. The application of these metrics in practice is thus likely to be best achieved by the engagement of a number of different specialists, with skills that allow the assessment of ecological, economic and social attributes and the interactions between these facets.

Given the engagement of practitioners with the required level of specialist skills, however, some of the assessment tools do lend themselves to more rapid approaches – inevitably associated with reduced levels of confidence in the output. In the case of the biotic assessments, the development of a "rapid" assessment is also limited by the length of time required for post-field processing of invertebrates (for both the dry season and the invertebrate assessment protocols). In the former, however, it is noted that the application of this protocol to wetlands in their dry season means that the overall assessment time may in cases be considerably shortened, in that there is in theory less need to wait for adequate inundation before carrying out an assessment. This means that decision-making around wetland identification, classification and appropriate use may be achieved more rapidly with the use of this protocol. The macrophyte index allows two levels of assessment, with the most rapid (a level 2 application of WET-Health) nevertheless requiring at least a full day (more for a large wetland) in terms of field collection and write-up.

Application of the remaining metrics all require minimum periods of specialist input of between one and five days, and it is noted that in many cases there may be a need to apply more than one metric or protocol to allow an adequate understanding of the particular issues affecting the present or likely future condition of a wetland or suite of wetlands. This aspect is elaborated on in Section 6.5.

Assessments that are required to provide high confidence input into decision making around wetland use or management should be carried out by personnel with specialist wetland knowledge. Requirements that these should be performed by non-specialists and in a time-frame of only a few hours are unrealistic and are also unlikely to result in added value in many decision making contexts. Where specialist input into the interpretation of field and spatial data is utilized, however, it is reasonable to assume that assessment outputs will be carried out a higher level of confidence, can be based on broader-based assessments requiring in some cases less data (i.e. “rapid” assessment) and may thus result in the faster generation of outputs that can feed into useful decision making processes. The need to collect more detailed, quantitative baseline data across the spectrum of wetland types and disciplines has, however, been highlighted throughout the WHI programme. In this context, it is strongly recommended that wetland assessment in South Africa should actively seek to improve the level of baseline data that are available for improved understanding of wetland structure, function and interactions with human and other systems.

6.5 The context for application of different WHI assessment tools

The assessment tools developed in the WHI programme lend themselves to application in a range of different contexts. Table 6.2 highlights the most relevant areas for the application of each tool – it is noted that the application of several tools may be necessary in some contexts, depending on the particular issues at stake. The selection of the most relevant tool to use in each case is in itself an aspect requiring specialist input, which takes cognizance of the range of likely issues to be affected, and their significance and ramifications, as well as the level of confidence that should reasonably be required in each assessment.

6.6 Tools for the interpretation and integration of the WHI assessment outputs

A critical aspect of environmental assessment is determining thresholds of response to change. This applies both at the level of the ecosystem (an understanding of the thresholds at which an ecosystem will respond to particular identified levels of change) and in terms of human intervention (at what threshold of identified change should a management intervention take place). Establishing such thresholds of change for different processes / biota / other variables in different wetland types, eco-regions or contexts has not formed a part of the present WHI programme. Identification of thresholds of management intervention has not been addressed in terms of the programme either. It is noted however that the long-term efficacy of any wetland management, conservation or rehabilitation programme implicitly depends on an understanding of such issues, and it is strongly recommended that these be addressed in future wetland research programmes. In such a context, the tools developed in the present WHI programme could be more finely tuned to provide input into the relationship of key aspects of assessed wetlands to such pre-defined “thresholds” of change.

Table 6.2: Summary of the major applications of different wetland assessment tools and protocols developed as part of the WHI programme. 1 (light shaded): The tool has some relevance to this application 2 (dark shaded): The tool has high relevance to this aspect.

METRIC NAME	**APPLICATION**								
	Broad scale biodiversity and conservation planning	Catchment / wetland management plans	Ecological Reserve determination	EIA assessment	Monitoring and auditing of conservation outcomes	Rehabilitation planning and management	Conservation lobbying	Financial incentive schemes / trade-offs	Strategic Environmental Assessments
TOOLS FOR THE ASSESSMENT OF WETLAND BIOTA									
Invertebrate Index	2	2	2	2					
Macrophyte Index	2	2	2	2	1	2			
Protocol for the assessment of wetlands in their dry season	2			2	1				
THE DEVELOPMENT OF TOOLS FOCUSING ON WETLAND ECOSYSTEM SERVICES									
Land cover change metric	2	2	1	2	1	2	1		1

Loss of function metric		2	1	2	1	2			
Protocol for the quantification and valuation of wetland ecosystem services	1	1	2	1	1	1	2	2	2
TOOLS FOCUSING ON SOCIO-ECONOMIC CONDITIONS AND SUSTAINABLE WETLAND USE									
Wetland Livelihood Value Index	2	2	2	2	1	1	1	2	2
WET-SustainableUse	1	2		1	1	2		2	1

7. WAY FORWARD

7.1 Achievement of the original programme objectives

The main aims of the Wetland Health and Importance Research Programme were listed in section 1.3. The extent to which each of these was achieved is discussed below.

Objective 1: *To develop tools for assessing wetland environmental condition that will address the major needs of users in South Africa.*
Development of a rapid bioassessment tool (possibly a "SASS for wetlands") was a high priority within the WHI research programme since this was (and still is) seen as a major gap in the tools available for management of wetlands in this country. Unfortunately, this was not an outcome of the programme because of the following reasons:

- work using both invertebrates (macro- and micro-) and plants showed that there is a high natural variation in environmental drivers within our wetlands and as a consequence biodiversity is high. This was shown for the Western Cape, but is also likely to hold for other areas of the country. Thus, indices of environmental condition that are developed using invertebrates or plants will only be applicable to a localised area and/or a particular wetland type;
- in the case of invertebrates, because the natural variation in depression wetlands is so high, the species found there tend to be "generalists" adapted to a wide range of conditions and therefore not particularly useful as indicator species; and
- for the entire country, there is a lack of basic information on the distribution of faunal and floral wetland species and lack of basic ecological understanding.

Despite the above challenges, indices were developed both for invertebrates and for macrophytes, which are applicable to localised areas in the W. Cape. The steps that need to be taken to develop equivalent indices for other areas of the country are presented in the reports.

The results from the three bioassessment projects (i.e. the invertebrate index, the macrophyte index and the dry condition index) do indicate that before *rapid* tools for measuring wetland environmental condition can be developed (indeed if they ever can for South Africa's highly diverse wetlands) a deep and thorough understanding of the ecological functioning of these systems (including comprehensive species lists) is required.

Objective 2: *To develop tools for assessing wetland socio-economic importance that will begin to satisfy the needs of users in South Africa.*

Through the tools that were developed in the socio-economic component of this study, the above objective was attained. It is now important that the tools are applied in different parts of the country, to different wetland types and in differing socio-economic contexts, and that the results from those applications are examined critically.

Objective 3: *To develop a protocol to assess the loss of wetland function through degradation.*

This objective was attained and is reported in Ellery *et al.* (2010). As for the socio-economic tools, this also needs to be refined and tested by application to real wetland systems.

Objective 4: To implement a communication programme to advise the use of assessment techniques developed in the programme.

This objective was carried out through presentations at various conferences, the WHI website (http://www.fru.uct.ac.za – then follow the WHI link), and the final reports.

7.2 Additional research and development requirements

The following research needs were highlighted in the individual projects:

7.2.1 Aquatic invertebrates as indicators of human impacts in South African wetlands (Bird 2010)

- Despite relatively poor bioassessment results for isolated depression wetlands in the Western Cape, a prototype framework for a numerical biotic index was developed during this study (essentially a modification of the SASS river index). This needs to be tested in other wetland types and regions of South Africa in order to further elucidate the relationship between wetland environmental condition and invertebrate response.
- The lack of clear indicator taxa for seasonally inundated wetlands investigated in this study is likely to be a common pattern in seasonal wetlands throughout South Africa due to the ‘generalist-type’ adaptations of taxa to these transient environments but more research in other areas of the country is required to confirm this prediction. Research effort towards the development of aquatic invertebrate indices in South Africa should rather be concentrated on perennial wetlands. This recommendation is

also relevant in the context of developing wetland indices using other biotic assemblages (e.g. diatoms) in that more specialist taxa are likely to inhabit perennial wetlands and thus bioassessment research for other biotic assemblages is expected to be more fruitful in perennial environments.

- Evidence from this project suggests that microcrustaceans are not useful for inclusion in wetland bioassessment indices in South Africa. This conclusion is reached partly because of the laborious enumeration and identification procedures involved and partly because of the lack of good indicator patterns observed in this study. More research in other wetland types and regions would offer clarification of this issue.

7.2.2 Development of a tool for assessment of the environmental condition of wetlands using macrophytes

- Collection of baseline ecological information such as taxon distribution and associated environmental parameters would facilitate the expansion of the potential for bioassessment in South Africa. Collation of existing strategic environmental impact assessment reports that deal with wetland plants would potentially assist the expansion of baseline data. Floristic- or phyto-sociological studies and classification of wetland vegetation types would also facilitate this process and aid the identification of species that indicate certain reference environmental conditions. This approach would also help define the vegetation classes and, as a result, inform which geographical areas would need separate bioassessment indices due to differences in reference or natural species assemblages.
- The development of clearly defined functional groups of plant taxa that are recognizable by trained technicians (rather than wetland botanists) would:
  - increase the number of personnel able to apply macrophyte bioassessment indices; and
  - decrease the need to identify taxa to species level thereby decreasing the field work and data processing time required for assessment.
- Determination of which habitat or hydrological zone in wetlands provides the most accurate reflection of present environmental condition in terms of the species assemblage that it contains would reduce the need to sample all zones within a wetland. This would again reduce the time and complexity of macrophyte assessment.

7.2.3 The assessment of temporary wetlands during dry conditions (Day et al. 2010)

- Links between crustacean taxa and various water quality, hydrological and physical aspects require further investigation under controlled conditions. Alternately, or in addition, more wetland sites need to be sampled in order to strengthen statistical results regarding environmental variables and community structure, and to provide a more comprehensive range of anthropogenic effects.
- This project provides a useful platform from which to conduct further studies, which will increase scientific understanding of life history patterns and drivers of the invertebrate fauna of temporary wetlands. The potential usefulness of various crustaceans, as well as diatoms and algae, as bio-indicators of environmental conditions (e.g. heavy-metal pollution, nutrient enrichment, anthropogenic salinity, toxicity) has been shown by several studies (ostracods: Ruiz *et al.,* 1995; copepods and cladocerans: Rinderhagen *et al.,* 2000; algae and diatoms: Charles, 1996; Schoeman, 1976; 1979; see also DWAF, 2004; Dallas and Day, 1984; Harding *et al.,* 2005). Similar hatching experiments to those illustrated in this study may well provide further insight into the use of these organisms as bio-indicators.
- Most importantly, we need to investigate regional differences in responses of invertebrates to *in vitro* incubation in order to obtain the greatest amount of information from incubation experiments. While the techniques themselves are probably adequate for propagules across the southern African region, optimal conditions of temperature and salinity are likely to differ from area to area, particularly when comparing propagules from summer- and winter-rainfall areas.
- It is known that, for certain species of fairy shrimp, eggs from a single batch do not all hatch after the first inundation. Instead, some will hatch only after multiple inundations, while the majority will hatch after being wet and dried only once (Davies and Day, 1998). Multiple inundations were not carried out in this study, but similar experiments to those conducted in this study and incorporating multiple inundations could prove valuable for understanding more about the biology of these organisms. Additionally, further investigations into the effects of drying of soil samples of wetlands impacted by longer hydroperiods is suggested since only a basic preliminary assessment was achieved in the present study.
- Our knowledge of the plants most characteristic of temporary waters is poor. The plant species lists should therefore be subject to ongoing refinement resulting from studies on habitat requirements of wetland plants.

7.2.4 Wetland ecosystem services and their valuation: a review of current understanding and practice (Turpie et al. 2010b)

- There is increasing pressure to develop rapid, cheaper methods for valuing wetlands in South Africa, particularly with the current emphasis on the determination of environmental flows under the South African National Water Act of 1998, but also due to the pressures of development. Up until now, international experience has shown that the use of rapid methods is potentially fraught with inaccuracy, especially regarding the use of benefits transfer. However, there have been some promising studies, which suggest that other rapid valuation techniques may be feasible, though these still require some level of data collection or surveys. This is an important area that requires more development and testing in South Africa.
- There are insufficient quantitative measurements of ecosystem processes in South African wetlands, which make valuing many of the benefits supplied by wetlands imprecise. Measurements of processes such as assimilation of nitrogen or phosphorus by wetlands have been made for only a few wetlands in this country. Allied to this the rates of such processes are likely to be highly variable both spatially and temporally and differ according to wetland type. The estimation of indirect use (ecosystem service) values requires in-depth understanding of the ecosystem under review, and inadequate ecological knowledge is often a constraint for their estimation. In the absence of the required ecological knowledge, assumptions need to be made in order to estimate values. This problem can to be overcome by conducting many projects measuring basic wetland ecosystem processes. This fundamental data is required in order for accurate valuations of wetland benefits to be made. It is also needed in order for rapid valuation tools to be developed.

7.2.5 A method for assessing cumulative impacts on wetland functions at the catchment or landscape scale (Ellery et al. 2010)

- The set of relationships developed in the project allow the likely provision of ecosystem services to be inferred from the determination of wetland health (in a qualitative manner). Thus, a practitioner should be able to infer the likely provision of several ecosystem services following the determination of wetland health. It should be recognised, however, that although the generalised trends are likely to be valid, the exact mathematical relationships (equations) are unlikely to be. The conceptual impact intensity-functionality models are presented as equations in this document in order to enable calculation. The authors recognise, however, that these need to be validated using extensive experimental data from wetlands from all over South Africa.

7.2.6 WET-SustainableUse: a system for assessing the sustainability of wetland use (Kotze 2010)

- Research is required into key wetland-processes focused at critical reference wetland sites, with the aim of allowing quantification of impacts of particular uses on wetland characteristics.
- Research into the ecological implications of wetland grazing, including differences in impact associated with different biomes and the interactive effects of fire and grazing needs to be carried out.
- Finally, independent testing both of the application of the metrics developed in WET-SustainableUse framework, and of the precision of its outputs is required.

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GLOSSARY OF TERMS USED IN THE WHI REPORT SERIES

Abiotic: not pertaining to living organisms; describes features such as temperature, rainfall, etc.

Adaptive management: a systematic process for continually improving management policies and practices by learning from the outcomes of management actions

Aerobic: having molecular oxygen (O_2) present (and therefore respiration using free oxygen)

Aestivation: a state in which animals completely lack measurable activity during hot and/or dry periods

Alien: of a plant or animal, one that does not occur naturally in an area

Allocate: to award a certain quantity of a "resource" (such a land or water) to a user or for different uses

Anaerobic: (= "anoxic") no molecular oxygen (O_2) present (and therefore respiration is not using free oxygen)

Anoxic: lacking in oxygen

ASPT (Average Score Per Taxon) values: the key output of the SASS (South African Scoring System) rapid assessment index; calculated by dividing the total SASS score for a site by the number of taxa scored

Assessment: evaluation; ecosystem assessment: in the present context, assessment of the condition, usefulness or value of a wetland

Bioassessment: the use of living organisms to assess environmental condition (usually with reference to some aspect of conservation)

Biodiversity: variety of living forms including the number of different species, the genetic variety within each species, and the variety of natural areas

Biotic: pertaining to living organisms (*cf.* abiotic)

Biotope: an area of uniform environmental conditions

BMWP (Biological Monitoring Working Party): a rapid macro-invertebrate bioassessment method developed for scoring the degree of impairment of streams in Great Britain

BMWQ: Spanish Biological Monitoring Water Quality score system; developed for the rapid bioassessment of Spanish streams using macro-invertebrates

Branchiopoda: primitive crustaceans (*q.v.*) belonging to the Anostraca (fairy and brine shrimps), Conchostraca (clam shrimps) and Notostraca (shield or tadpole shrimps)

Canonical correspondence analysis CCA: a type of multivariate statistical analysis

Capillary fringe: the zone of almost-saturated soil or sediment just above the water table

Carbon sequestration: The process of capturing carbon and keeping it from entering the atmosphere

Carrying capacity: the greatest number of organisms that can be supported sustainably per unit area of an ecosystem

Catchment: all the land area from mountaintop to seashore which is drained by a single river and its tributaries

CCA: canonical correspondence analysis, a type of multivariate statistical analysis

Chironomidae: non-biting midges

Chroma: the quality of a colour; in classifying soils, the relative purity of the spectral colour of a soil, which decreases with increasing greyness. Measured with a Munsell colour chart

Cladocera: water fleas such as *Daphnia*

Classification: of wetlands, the grouping into categories of systems with homogeneous natural attributes (such as aspects of hydrogeomorphology). NOTE: this is different from the 'classification' of water resources according to their departure from some reference condition as required by the National Water Act

Co-management: where the responsibilities for allocating and using resources are shared amongst multiple parties, often including local communities and a relevant government agency

Consumer surplus: a net benefit realised by consumers when they buy a good at the prevailing market price. It is the difference between the maximum price consumers would be willing to pay and that which they actually pay for the units of the good purchased

Contingent valuation: the use of questionnaires about valuation to estimate the willingness of respondents to pay for public projects or programmes

Copepoda: minute shrimp-like and mostly planktonic crustaceans (*q.v.*)

Crustacea: a large group of usually aquatic invertebrate animals characterized by two pairs of antennae and usually having many pairs of appendages

Cryptic: hidden

Delineation (of a wetland): the identification of the outer edge of the zone that marks the boundary between the wetland and adjacent terrestrial areas (based on soil, vegetation and/or hydrological indicators (see definition of a wetland))

Depression: a typically basin-shaped landform that increases in depth from the perimeter to a central area of greatest depth (may be flat-bottomed or round-bottomed) where water typically concentrates

Diapause: a period of suspended activity broken by an appropriate environmental cue

Direct use value: within the "total economic value framework" (*q.v.*), the benefits derived directly by an economic agent from the goods and services provided by an ecosystem; these include consumptive uses such as goods for harvesting and non-consumptive uses such as the enjoyment of scenic beauty

Discount rate: the interest rate at which future payments or income are discounted in a multi-period model. Reflects the time preference between consumption or income now or in the future

Discounting: the process of applying a “discount rate”. The rate of interest to cost and benefit flows that is used to find the equivalent value today of sums receivable or payable in the future

Economic growth: the percentage change in income, resulting from investment, increases in trade, size or scale effects, or technological progress

Ecoregion: a region defined by similarity of climate, landform, soil, potential natural vegetation, hydrology and other ecologically relevant variables

Ecosystem condition: the quality of an ecosystem relative to that of an undisturbed or fully functional state

Ecosystem services: the direct and indirect benefits people obtain from ecosystems, including provisioning of food and water, regulation of disease and flooding, spiritual, recreational and cultural benefits

Ecotoxicology: the study of the effects of toxic chemicals on the biotic constituents of ecosystems (see “toxicants”)

Endorheic: of a wetland, one that is inwardly-draining with no outlet

Eutrophication: the process whereby high levels of nutrients result in the excessive growth of plants.

Existence value: the value that individuals may attach to the mere knowledge of the existence of something, as opposed to having direct use thereof; part of non-use value

Explicit shared purpose: a purpose that is clearly stated and which was developed in an inclusive way, such that it reflects the interests of the different actors

FCI (Functional Capacity Index): used to indicate the degree (capacity) to which a wetland performs a given function under the HGM functional assessment method

Floodplain: the mostly flat or gently sloping wetland area adjacent to and formed by a lowland river, and subject to periodic inundation by overtopping of the channel bank

Flow accounts: used here to refer to production accounts in “natural resource accounts”, valued in terms of annual contribution to national income

Functional unit: a level 3 discriminator in the South African National Wetland Classification System hierarchy (Ewart-Smith *et al.,* 2006)

Fynbos: the low-growing vegetation found in much of the part of the Western Cape province which experiences a Mediterranean climate

Generalist: as used here; an organism that is able to thrive in a broad spectrum of environmental conditions

GIS: “Geographical Information System;” a computer-based system that stores, manages and analyzes data linked to locations of physical features on earth

Governance: the socio-political structures and processes by which societies share power

Gross domestic product (GDP): the measure of the total value of all the goods and services produced in an economy, less raw materials, and other goods and services used in the production process during some accounting period, usually a year; see “national income”

Gross income: “gross revenue”, or “turnover”, usually a private measure

Gross national product (GNP): similar to GDP but including income earned abroad by nationals, and excluding income transferred abroad by foreign owners; see “national income”

Gross output: gross revenue in economic terms, commonly the aggregate of all gross revenues in the economy

Gross revenue: in general terms, equal to the unit price multiplied by the quantity of units sold by a production unit

Groundwater: sub-surface water in the zone in which permeable rocks, and often the overlying soil, are saturated under pressure equal to or greater than atmospheric

Halophyte: a salt tolerant plant

Head cut: the uppermost point where the head-ward extension of a gully is actively eroding into undisturbed soil

Heleoplankton: floating vegetation

Helophyte: a marsh plant

Hillslope seep(age): see “seep”

Hydric soil: a soil that is exposed to conditions of saturation, flooding or ponding long enough during the growing season to develop anaerobic conditions in the upper layer(s)

Hydrogeomorphic (HGM) type: any land form characterized by a specific origin, geomorphic setting, water source, and hydrodynamic conditions; used as a system of classification of wetlands or portions of wetlands

Hydrology: the study of the properties, distribution, and circulation of water on the Earth

Hydromorphic: of soil, with properties (e.g. mottling, greyness) imparted by wet conditions

Hydrophilic: water-loving

Hydrophyte: any plant that grows in water or water-logged soil

IBI (Index of Biological Integrity): an integrative expression of the biological condition of a site that is composed of multiple metrics

Indicator species: a species whose presence in an ecosystem is indicative of particular conditions (such as saline soils or acidic waters)

Indirect use value: the benefits derived from the goods and services provided by an ecosystem that are used indirectly by an economic agent. For example, an agent at some distance from an ecosystem may derive benefits from drinking water that has been purified as it passed through the ecosystem

Infilling: dumping of soil or solid waste onto the wetland surface
Institutions: the formal rules, conventions and laws (e.g. marriage), as well as the informal codes of behaviour that constrain and direct societal activities and interactions

Integrated Environmental Management (IEM): an internationally accepted procedure for promoting well-planned development by ensuring that the environmental consequences of development are understood and adequately considered in planning and implementation

Interstitial: of animals, living between grains of sand

Invasive species: a species that has the capacity to out-compete and dominate the naturally occurring species and that can adversely affect the habitats (economically, environmentally and/or ecologically) that they invade

Inventory (of wetlands): a catalogue of their geographical position, number and characteristics

Invertebrate: an animal without a backbone

Larva: the free-living immature stage of an animal that is unlike the adult

Least impaired: pertaining to wetlands; those which have incurred a minimal degree of human impairment, relative to other wetlands in a region

Lentic: of standing waters (ponds, lakes etc.)

Livelihood: the capabilities, assets and activities required to make or gain a living

Lotic: of running waters (streams and rivers)

Macro-invertebrate: animals without backbones that are retained by a 500-1000 micron mesh (mesh size depending on definition used)

Macrophyte: a large plant; in wetland studies usually a large plant growing in shallow water or waterlogged soils

Management: the implementation of actions aimed at achieving a goal. It may encompass planning, organizing, staffing, directing and controlling

Marsh: a wetland dominated by emergent herbaceous vegetation and usually permanently or semi-permanently flooded or saturated to the soil surface

MCI (Macro-invertebrate Community Index): rapid bioassessment index used to score the impairment of New Zealand streams using macro-invertebrates

Metrics: used here as a summary measure of assemblage composition which shows empirical change along a gradient of human disturbance

Micro-crustacean: crustaceans of length greater than 63-153 microns (mesh size depending on definition used), dominated by the taxa Cladocera, Ostracoda and Copepoda in freshwater environments

Minimum tillage: of “tillage”: ploughing. Keeping disturbance of the soil to a bare minimum when cultivating crops

Mitigate: to reduce the impact of

Molapo: (= dambo) a grass-covered depression that fills with water during the wet season

Monitoring: the regular, systematic gathering of information based on observations and measurements

Morphology: structure

Mottles: of soils, variegated colour patterns on a uniformly-coloured background

Mulch: a protective cover, usually consisting of organic material (e.g. crop residues) that is placed over soil

Multivariate index: in a bioassessment context, models that seek to predict biotic assemblage composition of a site in the absence of environmental stress. A comparison of the assemblages predicted to occur at test sites with those actually collected provides a measure of biological impairment at the tested sites

Munsell colour chart: a standardized colour chart used to describe aspects of the colour and chroma (*q.v.*) of soil

National accounts: compilation of accounts to derive estimates of the "national income"

National income: the total net earnings of labour and property employed in the production of goods and services in a nation during some accounting period, usually a year. Commonly measured by the "gross domestic product" (GDP) the "gross national product" (GNP), and the "gross national income" (GNI)

Natural asset value: capital value of the stock of a natural resource

Natural resource accounts – the compilation of asset and "flow accounts" for natural assets, to complement the "national accounts"

Nauplius: the first larval stage of some crustaceans

Net national income: "gross national income" less depreciation (loss in value) of assets

Net present value: the present value of an investment, found by discounting all current and future streams of income or expenditure by a "discount rate"

Non-use value: see "existence value"

NTU: nephelometric turbidity units – the standard unit of turbidity

Numerical biotic index: in a bioassessment context**,** a simple index format involving the assignment of sensitivity scores to individual taxa, which are then summarized as a total score or average score per taxon from a representative sample of a site

OKASS (Okavango Assessment System): a modified version of the SASS index used for bioassessment in the Okavango Delta

Open access resource: a good or service over which no property rights are recognised

Open water: inundated areas characterized by the absence or minimal occurrence of emergent plants

Opportunity cost: the benefits foregone by undertaking one activity instead of another
Option value: the value of preserving an option (e.g. conserving a wetland) to use the services in the future

ORAM (Ohio Rapid Assessment Method): a rapid technique for assessing human impacts on wetlands in the state of Ohio, USA

Palustrine: of wetlands; those dominated by persistent emergent plants and commonly called marshes, floodplains, vleis and seeps

Pan: of depressional wetlands; those that are endorheic (*q.v.),* typically circular, oval or kidney shaped, usually intermittently to seasonally flooded, and with a flat bottom

pCCA: partial canonical correspondence analysis, a direct gradient analysis technique which allows one to separate out the effects of covariables (see "CCA")

Peat: soil material formed by layers of dead vegetation and consisting of a high proportion (usually taken as ≥20%) of organic matter

Perched water table: the upper limit of a zone of saturation in soil, separated from the main body of groundwater by a relatively impermeable unsaturated zone

Perennial: permanent; persisting from year to year

Phyllopoda: essentially the same as Branchiopoda (*q.v.*)

Plankton: aquatic organisms, usually very small, which drift passively with the surrounding water

Poaching: (= "pugging") the disruption of soil structure as a result of the repeated penetration of the hooves of livestock into wet soil

Podsol: a soil with an organic mat and a thin organic-mineral layer, above a light gray leached layer resting on a dark horizon

Podzolization: the process of podsol formation

Propagule: any structure (e.g. an egg or a spore) from which a new individual can be produced

Quiescence: inactivity

Ramsar: the Convention on Wetlands that provides the framework for international cooperation for the conservation of wetlands

Red Data species: all those species included in the categories of endangered, vulnerable or rare, as defined by the International Union for the Conservation of Nature and Natural Resources

Reference sites: those sites that are minimally impacted by human disturbance and that reflect the natural condition of a wetland type in a given region

Rehabilitation: of wetlands**;** the process of assisting in the recovery of, or maintenance of, a wetland that has been degraded

Resilience: of ecosystems; the ability to maintain functionality after being subject to perturbations

Resource rent or **economic rent:** the return a factor of production receives in excess of the minimum required to bring forth the service of the factor, or the surplus available in a "production unit" after accounting for the costs of production including a reasonable return to capital. Resource rent is the economic rent generated from use of a natural resource

Restios: plants belonging to the family Restionaceae, also referred to as Cape reeds

Riparian: relating to the banks of a river
Rotifera: minute ciliated aquatic animals

Roughness coefficient: an index of the roughness of a surface; a reflection of the frictional resistance offered by the surface to water flow

Runoff: total water yield from a catchment including surface and sub-surface flow
SASS (South African Scoring System): a system for the rapid bioassessment of water quality of streams in South Africa using macro-invertebrates

Saturation: of soil; that where the water table or *capillary fringe* reaches the surface

Sedges: grass-like plants belonging to the family Cyperaceae, sometimes referred to as nutgrasses

Sediment: solid material that settles to the bottom of a liquid; in wetlands sediments typically comprise sand-, silt- and clay-sized particles

Seep: a non-depressional wetland area located on a clear incline, dominated by colluvial (i.e. gravity-driven) processes and characterized by subsurface flow entering from an upslope direction

Seepage: see "hillslope seep"

Social accounting matrix (SAM): an economic input-output model of the national economy, used as a tool for impact analysis. Expands the national accounts to show the linkages between production and generation of income and distribution of income

Social costs and benefits: costs and benefits as seen from the perspective of society as a whole

Soil saturation: soil is considered saturated if the water table or capillary fringe reaches the soil surface

Stakeholder: in the context of a wetland, any individual, group or community able to influence or be influenced by the management of the wetland
Stocking rate: the number of animal units per unit of land for a specified period of time. An AU is taken as equivalent to a 450 kg animal that consumes 10 kg of dry matter per day

Sustainable development: development that meets the needs of the present without compromising the ability of future generations to meet their own needs

Sustainable use (of wetlands): use within the resource's capacity to renew itself
Sustainable: that which can carry on indefinitely

Swamp: a permanently flooded reed-dominated wetland (in the US, a wetland dominated by trees)

Tardigrada: minute aquatic animals that are known for their ability to enter diapause for lengthy periods

Temporary zone: of wetlands, the zone that is alternately inundated and exposed

Temporary: of wetlands; those in which water is not permanently present

Tillage: the preparation of soil for agricultural purposes, by ploughing, ripping, hoeing or otherwise disturbing it

Total economic value framework: a widely used framework to disaggregate the components of utilitarian value, including "direct" and "indirect use value", "option value" and "existence value". Commonly applied to natural resources

Toxicant: a poisonous substance

Transpiration: the transfer of water from plants into the atmosphere as water vapour

Valley bottom (wetland) with a channel: a wetland type characterized by valley bottom areas with a well defined stream channel but lacking characteristic floodplain features

Valley bottom (wetland) without a channel: A wetland type characterized by valley bottom areas with no clearly defined stream channel, usually gently sloped and characterized by alluvial sediment deposition
Value added: the amount of economic value generated by the activity carried on within each "production unit" in the economy, the difference between the "gross revenue" of the production unit and the inputs purchased from outside the production unit. When aggregated for the whole economy becomes a measure of "national income"

Vlei: a South African term for a wetland; in the Cape, any wetland; in the rest of the country, a reedbed in a river course

Water quality: the suitability of water for a user (human or environmental) determined by the combined effects of its physical attributes and its chemical constituents

Waterlogged: saturated with water

WET (Wetland Evaluation Technique): rapid assessment technique developed through the US Army Corps of Engineers, which uses the presence or absence of a large set of wetland characteristics as qualitative predictors of wetland functions

WET-Ecoservices: a technique for rapidly assessing ecosystem services supplied by wetlands in South Africa (Kotze *et al.,* 2008)

WET-Health: a technique for rapidly assessing wetland health in South Africa (Macfarlane et al., 2008)

Wetland: "Land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which in normal circumstances supports or would support vegetation typically adapted to life in saturated soils" (South African National Water Act). Land where water is the dominant factor determining the nature of soil development and the types of plants and animals living at the soil surface (Cowardin et al., 1979)

Wise use: synonymous with "sustainable use"

WZI (Wetland Zooplankton Index): index developed for the assessment of wetland condition based on multivariate pattern analysis of water quality and zooplankton associations with aquatic vegetation in the Laurentian Great Lakes Basin

Zooplankton: animal plankton (*q.v.*)

APPENDIX 1

A CRITIQUE OF CURRENTLY-AVAILABLE SOUTH AFRICAN WETLAND ASSESSMENT TOOLS AND RECOMMENDATIONS FOR THEIR FUTURE DEVELOPMENT

By Malan, H.L.

August 2008[4]

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Rationale for the Study

Currently, there are various South African tools that have been developed for assessing different aspects of wetland environmental condition ("ecological health") and functioning. As part of the strategic overview of the research needs for wetland health and importance (Malan and Day, 2005), the need to compare and examine these tools was highlighted, with a view to identifying their strengths, weaknesses, as well as any gaps and overlaps. Three assessment tools were evaluated in this exercise, namely:

1. WET-EcoServices: a technique for rapidly assessing ecosystem services supplied by wetlands (Kotze *et al.,* 2008);

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[4] This is the date at which the review was finalised. Development or changes in the assessment tools may well have occurred subsequent to this.

2. WET-Health: a technique for rapidly assessing wetland health (Macfarlane *et al.,* 2008); and
3. The Wetland Index of Habitat Integrity (DWAF, 2007 (Editor: Rountree, M.)).

The Approach that was used

Several different approaches have been used to describe the condition of a wetland. These include:

- functional assessments, which examine the "goods and services" delivered, or potentially delivered, by a wetland;
- bioassessments which use a variety of floral and/or faunal groups to indicate the environmental condition of a wetland; and
- habitat assessments which quantify the impacts affecting a wetland.

Such assessment tools may be rapid, designed for non-wetland specialists or more comprehensive tools for in-depth studies by trained scientists. The literature pertaining to assessment of wetland condition has recently been reviewed (DWAF, 2004; Malan, Day and Marr, 2005; Malan and Day, 2005) and is therefore not repeated here. Key sources on this topic include (Adamus *et al.,* 2001; Brinson *et al.,* 1994; Butcher, 2003; Chessman *et al.,* 2002; Finlayson *et al.,* 2001).

The approach that was used in preparing the critique of assessment methods is discussed below. As noted by Kotze *et al.* (2005), assessment of wetland condition is not a straightforward process, and there is no assessment tool that can be used for all wetland types and in all situations. Thus a tool that is designed to produce a rapid assessment of environmental condition may use a different approach to one aimed at developing a detailed understanding of ecological functioning. For this reason, when evaluating the effectiveness of the tools, cognisance was taken of the aims of the technique in question. Furthermore, although considerable input from the respective tool developers was solicited, in order to test the tools in an objective manner, the actual implementation was carried out by members of the project team. The following steps were taken:

1. the latest versions of the tools were obtained, studied and any problems/uncertainties in their application were discussed with the developers;
2. the tools were then applied in the field in order to become familiar with them. Different types of wetland, in terms of classification type, socio-economic setting, and level of impact, were studied;

3. specific attention was given to considering the questions posed in Table A1;
4. challenges that arose during the implementation of the tools were discussed with the developers; and
5. results from the assessments were used to draw-up the current critique on the usefulness of the tools with regard to the needs of South African users.

Table A1. 1: Specific questions to be answered for each assessment tool

1. Does the approach seem sensible? Does it rest on a sound scientific basis (e.g. is a similar approach used in other countries?)
2. How well-developed is the method?
3. How user-friendly is the method, and what level of expertise is required?
4. What are the data-requirements and are they realistic?
5. What are the time-requirements?
6. Is there documentation of the method and how well written-up is it?
7. For tools that permit different levels of assessment (e.g. as in WET-EcoServices and WET-Health) – do they give the same answer?
8. Allied to the above, if an assessment of a wetland is made after a quick site visit, or alternatively, a lengthy field visit, are similar results obtained?
9. How reproducible are the assessment results for the same wetland with time/season.
10. How reproducible are the assessment results for the same wetland with different assessors.
11. What is the range of wetland types that can be assessed with each method? Do adjustments need to be made for the different types and if so, what?
12. Can each method be applied successfully to wetlands in different geographical regions? Do adjustments need to be made in the approach and if so, what?
13. How are the results altered if a fundamental mistake is made at the beginning (e.g. if the wrong HGM type is assigned)?

The following wetlands were studied:

Zeekoeivlei/Rondevlei seasonal wetland (Cape Town)

Soetvlei (Cape Town)

Ratelsvlei (Agulhas Plain)

Lets'eng-la-letsie (Lesotho)

Kuils River (at Mfuleni, Cape Town)

Dawidskraal wetland/linear hillslope seep/Bass Lake (Betty's Bay, W. Cape)

Nylsvley (Mpumalanga)

Langvlei and Ramkamp wetlands (Kamiesberg, Northern Cape)

(Franklinvlei in E. Cape) – this was investigated as part of a Reserve Determination Study undertaken by Rountree, M. *et al.* at which the author was an observer.

Because the assessment tools have been continually evolving during the course of this project, the output of this review has taken the form of on-going input to different versions. Presented below are conclusions and suggested recommendations for future developments in the above (or other) wetland assessment tools.

Conclusions and Recommendations

Major comments and recommendations

1.1. All three-wetland assessment methods (WET-Health, WET-EcoServices and the WIHI) are valuable tools that have an important place in the management and conservation of South Africa's wetlands and their authors should be congratulated on their foresight in developing them. As they stand, all three tools are fully usable and are at the point where they need to be employed in the field by a range of different users on different wetland types and in different parts of the country. Because of the diversity of wetlands in terms of their functioning, the complexity of the socio-economic settings and the impacts they are subjected to, it is only by extensive trialling of the tools that all the problems will be identified. It is important though that insights and experiences gained be collated and used to refine subsequent versions of the tools.

2.1. Three methods for assessing environmental condition ("ecological health") were evaluated namely; WET-Health level 1 and 2, and the WIHI. Although WET-Health is titled "a technique for rapidly assessing wetland health" application of level 2 to a single, small wetland would probably take an average of 2 days (3-4 hours preparing maps, 1 day in the field, 4-5 hours completing datasheets). Writing the report of the results takes several more days (but this could possibly be shortened – see later). Application of level 1 WET-Health and the WIHI is much quicker, but as is to be expected, the level of confidence in the results, and the degree of understanding of wetland functioning and the reasons for the impacts is likely to be more superficial than obtained using the detailed WET-Health level 2 approach. There is a decided need for both a detailed and a rapid assessment method.

2.2. WET-Health level 2 is an excellent detailed method that will be invaluable in Intermediate or Comprehensive Reserve determinations for establishing the Present Ecological State and trajectories of change. It could possibly be extended by adding other components (e.g. a water quality module, or module for depressional wetlands – see later). WET-Health also provides a good framework for application of other assessment approaches for wetlands, for example biotic indices, and evaluation of the sustainability of use.

2.3. It is recommended that WET-Health level 1 and the WIHI be combined to produce a user-friendly, yet reasonably rigorous assessment tool. As the situation now stands, both tools have good features, but both also have weaknesses. The WIHI is user-friendly in terms of the easily understandable manual and the attractive user-friendly spreadsheet-model. The Geomorphology section is also simple to use, unambiguous, and appears to offer reproducible results (in terms of different users returning similar values). It is felt though that the hydrology section, and in particular the consideration of different land-uses in the catchment and in the wetland is not detailed enough. For example, one impact is listed as "vegetation clearing/loss/alteration" which is extremely broad. As a consequence, some impacts will remain undetected (or at least unreported) and many wetlands differing in degree of impact will ultimately be lumped into the same PES category. WET-Health level 1, on the other hand, is backed by the detailed reasoning that has gone into the level 2 tool, and is more scientifically rigorous in its approach, although it is not presented in such a simple, user-friendly way as the WIHI. Despite the fact that the tools are aimed at people with different levels of expertise, careful consideration should be given to combining the two methods, so that the best features of both systems are included. Indeed, it is probably counter-productive for the country to have two different rapid assessment tools. Differences in the level of expertise of the assessors could be dealt with by assigning different levels of confidence in the results.

2.4. WET-EcoServices as it stands can be applied as a desk-top (level 1) and more detailed (level 2) approach, which are both fairly rapid and straight-forward to use.

3.1. Because of the complexity and diversity of wetlands and of the ecological processes occurring in them, it is important that training be available in the use of these tools. This is essential for all the tools, but especially for WET-Health, which is the most detailed of the methods. To achieve this end, structured and standardised training needs to be provided. [This could potentially be through WESSA's WATER programme].

3.2. It is important that the training has a large field component which involves studying aerial and ortho-photographs, and identifying and assessing important structures and features in the field. Only after considerable experience, is it for example, possible to distinguish areas of sediment deposition in the field and from aerial photos. The initiative should link up with the on-going wetland delineation training scheme.

3.3. To aid in the above, it might be useful if an electronic “photograph album” of various wetland features could be produced (e.g. erosion gullies, different HGM types, alluvial fans, dykes). Albums of wetland plants (with photographs) would also be useful (and ultimately, regional field guides). This training material would be useful for all the assessment tools.

3.4. Both WET-Health and the WIHI use a structured method to assess environmental condition (this is naturally more detailed in the more comprehensive WET-Health). The authors have endeavoured to capture their collective (extensive) experience in wetland field assessment and incorporate it into the scoring systems. To a large extent they have been successful. This is, however, a difficult thing to do and there is a large element that cannot easily be incorporated in a form understandable to less experienced field workers and cannot be quantified in the form of easily measurable parameters. Thus, to some degree all the tools depend on expert judgement and experience. Consequently, in order to obtain reproducible and accurate assessments it is important that assessors using these tools have the same set of “internal scaling.” To aid in the training process, brief “case studies” (with many photographs) of real wetlands should be produced. These should range from almost pristine wetlands (“A” category) to extremely impacted (“F” category), but wetlands falling within this range in terms of environmental condition should also be included.

4.1 From experience, we have found that one of the most difficult steps in the assessment process (using any of the tools) is correctly assigning the HGM type. This can be tricky, especially when there is a mosaic of wetlands in a setting that experiences a high water table (e.g. coastal plain systems), and yet the choice of HGM type can have a marked effect on the results. To a large extent this problem can probably be avoided by training. To avoid confusion it is imperative that the same system of wetland typing (classification) be used by all wetland scientists in the country, and that this is coherent with the manuals for the assessment tools.

5.1. The situation will be frequently encountered where no historical photographs/information is available, and it is suspected that the present condition of the wetland is very different from the reference condition. This is a problem that is not easily surmounted. Perhaps as more becomes known about the wetlands in this country and our understanding of how wetlands respond to external impacts, it will be easier to deduce the reference condition of a given wetland.

6.1. Attention needs to be given to the form in which assessment results should be recorded. At the moment in the case of the WIHI, the spreadsheet-model (which can be printed out) provides a fairly good record of the assessment (although some further additions could be made – see later) and care needs to be taken that enough notes are made during the site visit. In the case of a level 2 (detailed) WET-Health assessment, at the moment, writing up the report is rather onerous. This could be shortened by developing a report template which would include the results tables (with possibly ancillary tables, if required, in an appendix), place for results, and importantly, place for comments and reasoning.

6.2. Evaluating the functions performed by a wetland by using WET-EcoServices is a simpler, more straightforward process than evaluating the environmental condition using WET-Health and as a consequence recording the results is not so onerous. Consideration could be given to refining the spreadsheet-model, however, for this tool also so as to provide a good record of all the results (and the reasoning behind them).

7.1. For all the tools, thought needs to be given as to how repeat assessments of the same wetland should be carried out (and the results recorded). For example:

- In WET-Health level 2 (and possibly for the other tools) one of the outcomes should be a list of what aspects need to be monitored (for example encroachment of terrestrial vegetation). This type of information is recorded during the assessment, especially when considering the trajectory of change, but needs to be highlighted. It would be particularly useful this were couched as specific management actions.
- Photographs need to be linked to the datasheets. Also records of where fixed-point photographs were taken need to be noted (so that they can be re-taken on subsequent visits).
- Perhaps in the manuals for the various tools, which parameters are likely to change depending on land-use in the wetland/catchment and impacts etc. with time can be highlighted,
- For all the tools, thought needs to be given to what will happen to the results of the assessment. Ultimately, the results need to eventually be fed into a national database of wetland information (linked to the National Wetlands Inventory).

8.1. There are embryo water quality modules in both WET-Health and the WIHI, but neither is complete. Water quality is an extremely important driving variable that needs to be included in a thorough assessment of wetland condition. Currently, there are other initiatives also underway that are considering wetland water quality including:

- Work that has been done for the rivers physico-chemical ecostatus approach (Kleynhans *et al.*).
- Development of the wetlands water quality component for Reserve Determinations (Malan *et al*. *in prep*.) – which develops the WIHI approach further.
- Work being undertaken by Jaganath, C. (University of KZN) and Ellery, W. (Rhodes University) on the cumulative impact of wetland loss on water quality (as part of the Wetlands Health and Importance Programme).
- Possibly the up-coming project on wetland buffers.

It is important that there be synergy between these projects. A well-thought-out, validated model based on land-use contaminants generated, would be extremely useful in helping to establish the PES of wetlands (and possibly of ephemeral rivers). This could be developed into a water quality assessment module that could be added to WET-Health (and possibly in a shortened form to the more rapid assessment methods).

9.1. At the moment it is not entirely clear how to assess the ecological health of depressional wetlands using the current tools. In WET-Health, it is specifically stated in the Geomorphology module that pans/depressions are not considered. No mention is made in hydrology or vegetation modules of this HGM type. At the moment the WIHI can only be used for floodplain and channelled valley-bottom wetlands (other HGM types will be considered in the second phase of the project). Attention should be given to developing a module in WET-Health (and at a simpler assessment level) for assessing the environmental condition of depressional wetlands.

9.2. Linked to this is the problem of how to assess wetlands that arise from the presence of an elevated water table. These are often depressional wetlands, and often found on the coastal plain. The existing hydrological assessment approaches in WET-Health and the WIHI do not currently cater for these systems.

9.3. Another consideration, which is often found in the above situation, is where wetlands are situated in such large, flat catchments, that is difficult (and perhaps irrelevant) to delineate the catchment boundary and calculate areas of different land-use (as is the current approach). Perhaps in such cases a better approach would be to rate the extent and intensity of different impacts within a certain radius of the wetland. Mention is made of the proximity of an impact (e.g. surface hardening) to the wetland in WET-Health and how this can be considered and used to adjust the intensity of an impact. This needs to be taken further.

9.4. Factors that would need to be considered in an assessment of depressions include water quality, excessive siltation due to activities in the catchment and encroachment of macrophytes. From an examination of the present approach in WET-Health, it would seem that fairly minor changes would need to be made to the existing hydrology, geomorphology and vegetation modules to cater for depressional wetlands. Endorheic wetlands are particularly vulnerable, however, to pollution, and therefore in order to carry out a thorough assessment, water quality would need to be included.

9.5. Thought also needs to be given to the ecosystem benefits provided by depressional wetlands and whether these are adequately catered for in WET-EcoServices.

10.1. One of the ultimate aims in further development of wetland assessment tools (both for environmental condition and ecosystem services) is to incorporate some form of predictive capability. Thus, for a given development scenario (for example a reduction in the water allocation to a wetland), it would be extremely useful to be able to predict the effect on wetland health and the benefits ("goods and services") it would be able to supply. This predictive capability might initially be qualitative, but ultimately, to be useful, would need to be quantitative. To develop fully predictive, accurate models is an ambitious task that requires detailed understanding of wetland ecological processes. Given the current level of understanding, this may not be possible in the short-term, but should be a long-term goal.

11.1 There appears to be scope for extending some of the wetland assessment tools to ephemeral river systems and this should be investigated further.

12.1 The vegetation module of WET-Health pragmatically takes account of what plant species should not be in a wetland (i.e. alien species or ruderal indigenous species). Subtle changes in species composition may not be picked up during the assessment. For example, in the Kamiesberg project where, due to antecedent agricultural activities, renosterbos (a species indigenous to the area and found in pristine wetlands) abundance is likely to have increased relative to the natural condition. This is, however, a rapid (not detailed) assessment method. This problem can probably be circumvented by interviewing local vegetation experts (as is recommended in WET-Health).

Minor recommendations

WET-Health

1. As WET-Health is a fairly comprehensive assessment tool (despite the title!) perhaps future versions should consider the possible impact of climate change on hydrology?

2. Some adaptations to different regions of the country appear to be required. There are features (e.g. scores for sugar cane) that are not relevant to wetlands in other parts of the country, and other features (e.g. the relative water consumption of vineyards and wheat) which may need to be included for wetlands of the Cape. Mining activities within wetlands is listed as an impact in WIHI, but not in WET-Health or WET-EcoServices. These issues will be highlighted, as the tools are trialled in different areas of the country.

3. As part of the WET-Health procedure, any signs of excessive deposition of sediment, for example alluvial fans, needs to be noted by the assessors. Yet it is difficult for assessors who are not expert geomorphologists to identify these features and further, to know when they are a natural feature and when they are a result of impacts in the catchment.

3.1 Allied to the above, in the Geomorphology module, indirect and direct indications of geomorphological impacts are considered. Is there a risk that this may lead to "double-counting" of impacts?

3.2 Currently, the impact of upstream dams on sediment transport is not considered in the case of non-floodplain wetlands. Yet in the case of Davidskraal wetland, Betty's Bay, which is a channelled valley-bottom wetland, this feature has resulted in extensive downstream erosion (through "capture" of a road).

4. The current method does not explain clearly how to calculate the change in surface roughness when there are several different land-uses (disturbance units) within a wetland. Similarly if there is more than one type of structure impeding or draining flow it is unclear how to score the various parameters. More guidance is needed on this.

5. WET-Health currently takes changes in flow seasonality or periods of non-flow into account by using expert judgement to adjust the assessment scores. These are important impacts and should perhaps be included more explicitly (by including these aspects in the scoring tables).

6. Loss of organic sediment due to direct activities such as peat mining, burning is recorded in the appropriate assessment table. Loss due to erosion of sediments is currently not included, and needs to be added.

6.1. A further refinement is required when calculating the impact of organic sediment loss. Currently, the extent of the entire HGM unit is used in the calculation. In practice, however, only a portion of the HGM unit may contain organic sediments, and this refinement needs to be added to the protocol.

WET-EcoServices

1. The addition of well-documented, clearly reported test cases from actual wetlands would be a very useful addition. This should cover a range of wetland types, socio-economic/land-use settings and geographic regions.

2. Consideration should be given to allocating wetlands in urban areas an additional score in WET-EcoServices. Many of these wetlands may have only small benefits in terms of biodiversity and hydrological functioning. Nevertheless, in acting as a green area in an urban landscape they are extremely valuable.

3. A further development of the tool would be to investigate summing the scores obtained for individual ecosystem services in order to obtain an "overall value." In such a process, different benefits may need to be weighted higher than others and so careful thought would need to be given to this. This would, however, need to be done whilst also taking into account the size and proportion of different land-uses in the wetland. Thus, a small wetland that is likely to be very effective in flood amelioration would have the same score as a really large system. This could possibly be refined further by introducing some type of scaling factor. [Note: this concept is furthered in the WHI report "A method for assessing cumulative impacts on wetland functions at the catchment or landscape scale" (Ellery *et al.* 2010)].

The Wetland Index of Habitat Integrity

1. Perhaps the current title "Manual for the assessment of a Wetland Index of Habitat Integrity" should be simplified (for example to "The Wetland Index of Habitat Integrity").

2. Currently, the extent and intensity of an impact are scored in this approach (which makes it compatible with the approach used in WET-Health). In addition, several individual parameters need to be ranked and weighted by the user (to make the process compatible with the other array of DWAF Ecostatus tools). Consequently, sometimes the process of scoring impact is extremely complicated. It is this author's opinion that it is not really helpful to request users to rank and weight different impacts, especially if the tool is aimed at non-wetland scientists.

3. In the spreadsheet model, different land-uses in a wetland are listed and the extent of each recorded. If more than one impact occurs the activity that has the greatest impact is listed. There is a danger here that less important impacts will go unrecorded.

4. Consideration should be given to adding a "Trajectory of change" of the wetland (in addition to monitoring key issues, as mentioned in the previous section).

5. The danger to wetland hydrological functioning that is posed by the presence and formation of erosion gullies needs to be emphasised. This is especially important if the tool is to be used by non-wetland scientists.